

Do children use logic to spell logician? Implicit versus explicit teaching of morphological spelling rules

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Background. Intervention studies have reported the advantage of teaching children about morphemes for spelling, but direct comparisons between explicit and implicit teaching have been examined systematically in relation to only a few morphological rules.

Aims. This study compared explicit versus implicit teaching of the functional rule for the conservation of stem morphemes in derived words in English (e.g., *logic* is conserved in the derivative *logician* in spite of changes in pronunciation).

Sample. Participants ($n = 90$; 7- to 9-year-olds) were drawn from three schools with a diverse intake.

Methods. The design included a pre-test and two post-intervention tests. Participants were randomly assigned to one of three groups: an explicit group, taught about stems and their conservation in derived words; an implicit group, exposed to the same stems and derivatives without explicit teaching; and an unseen control group. At pre- and post-test, the children's spelling of stems in derivatives was assessed. The interventions involved practice games in which the children spelled derived words after seeing the base forms; the explicit group discussed the connection between the spellings, whereas the implicit group did not.

Results. Analyses of variance revealed that explicit teaching led to more significant spelling improvements than implicit or no teaching, and this effect held at both post-tests.

Conclusions. It was concluded that explicit teaching of the stem conservation rule in derived forms combined with appropriate practice games shows a sustained effect on spelling. The evidence supports explicit teaching of this morphological rule in classroom practice.

The English orthography includes functional and formal rules. Functional rules relate to the representation of phonemes (i.e., units of sound are represented by particular letters), and of morphemes (i.e., units of meaning are represented by specific stem and suffix spellings) (Carney, 1994; Jaffré, 1997; Venezky, 1970), whereas formal rules refer to permissible letter sequences and positions (e.g., no double consonants are allowed at the beginning of words: Ferreiro & Teberosky, 1983; Lehtonen & Bryant, 2005; Venezky,

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1967). This results in such a complex system of rules that Godfrey Dewey (1971, p. 4) and Bernard Shaw considered English orthography as 'chaotic' and 'impossible' to learn (Kessler & Treiman, 2003). However, they recognized only the functional rules relating to grapheme–phoneme correspondences, which led to the perception that there are many inconsistencies in English spelling.

These apparent inconsistencies are evident when different phonemes can be spelled in the same way. For example, *kissed* /kɪst/ and *opened* /'əʊpənd/ end in different sounds but have the same final spelling, *-ed*, because they are regular verbs in the past; between 8 and 9 years of age, most children adopt *-ed* for spelling regular verbs without overgeneralizing it to irregular verbs (Nunes, Bryant, & Bindman, 1997). The same sounds can also be spelled differently: The stems (e.g., *logic*, *elect*, and *confess*) in *logician*, *election*, and *confession* each have the same consonantal sound /ʃ/ (i.e., *sh*), but they have different spellings (*c*, *t*, and *ss*) because the stem is conserved in derived words in spite of changes in pronunciation, reflecting a principle that Venezky called 'the visual identity of meaningful word parts' (1999, p. 9). These stem spellings are not easily mastered: In a large sample ($n = 1,414$) of 9-year-olds in the United Kingdom, Dreher (2015) found that approximately 31% correctly used *c* in *magician* and *electrician*. This example illustrates the challenges for children in mastering a complex rule system.

This description does not in itself address whether people need to be explicitly taught these rules to attain competence in spelling. Ever since Chomsky's (1957) publication of 'Syntactic Structures', the question of the relation between rule-like behaviour and rule knowledge has intrigued psychologists and educators, because adults can make consistent judgements of the grammaticality of sentences but cannot explicitly describe the rules of grammar in their native language. Chomsky referred to the adults' knowledge as 'intuitive knowledge of grammatical sentences' (Chomsky, 1957, p. 13) and concluded that it was innate (Chomsky, 1980), but psychologists turned to research on how this implicit, rule-like behaviour is acquired. Correct spelling is undoubtedly rule-like behaviour and one can hardly argue that it is innate given the cultural nature and huge variation of writing systems. The question is whether spelling is 'caught' by children implicitly as they read and write, or if it needs to be 'taught' (Peters, 1967), and if so, how it can be best taught.

To uncover whether complex rules can be learned without teaching, psychologists created what they called *artificial grammars* (AGs) (e.g., Reber, 1967). AGs follow formal rules for spelling in the absence of functional rules as the grammars are a series of permissible or non-permissible letter strings (e.g., strings could start with *T* or *V*, they could end in *S*, and *S* could never precede *P*). In a typical AG task, adults are exposed to letter strings, which are to be remembered; nothing is said about rules. Subsequently, the participants are shown a series of strings not seen previously and are asked to judge whether they follow the complex rules of the AG. Across studies, the participants performed the judgement task with above chance accuracy, which led Reber to conclude that they had learned the rules implicitly by mere exposure to exemplars. Children's ability to learn AGs implicitly has also been investigated (e.g., Ise, Arnoldi, Bartling, & Schulte-Körne, 2012; Samara & Caravolas, 2014; Steffler, 2004). The studies used unpronounceable and pronounceable letter sequences with only a few rules (e.g., before a final *T*, consonants are doubled [*GOSS7*]; before a final *K*, no consonants are doubled [*DAFK*]). Children aged 9–12 years performed above chance on untrained test items. Thus, these studies indicate that both children and adults may learn something about the formal rules of an AG implicitly, in the absence of teaching.

Implicit learning of *spelling* in research has focused mostly on formal rules and the functional rules relating to morphology because phonological rules are typically taught explicitly in school (for formal rules, see Deacon, Leblanc, & Sabourin, 2011; de Bree, Geelhoed, & van den Boer, 2018; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Treiman & Wolter, 2018; for functional rules relating to morphemes, see Bryant, Nunes, & Snaith, 2000; Kemp & Bryant, 2003). Throughout studies, researchers asked children and adults to make judgements about the spelling of pseudo-words which either respected the rules or not: For example, in French some consonants can be doubled whereas others cannot (e.g., *ll* is permissible but not *jj*). In the study by Pacton et al. (2001), children aged 6–9 years judged the pseudo-word *ullate* as permissible and *ujjate* as non-permissible at above chance level, even though the rule is not taught in French schools, but they could not explain why they made such judgements. These studies suggest that children may learn spelling rules incidentally and implicitly.

A few studies have investigated implicit learning of spellings through reading with high school and college students, but these focus on word-specific learning of word or pseudo-word spellings by rote rather than on rule learning (e.g., Gilbert, 1934; Ormrod, 1986; Pacton, Borchardt, Treiman, L  t  , & Fayol, 2014). For instance, Pacton et al. (2014) asked French students to read pseudo-word spellings (e.g., *tiddunar*) embedded in texts for the purpose of answering questions afterwards. The students improved more on spelling words included in the texts than on other spellings, which indicates that students often learn spellings implicitly while reading, without the intention to do so. Although the participants were learning specific spellings rather than rules, previous results on implicit learning are corroborated.

As children appear to learn something about rules implicitly, an interesting question to consider is whether exposing children to exemplars of a rule through *teaching* is an effective way of improving spelling. Intervention studies show that teaching children functional rules relating to grapheme–phoneme correspondences (e.g., Bradley & Bryant, 1983; for a review, see Ehri, 2003) and to morphemes improves their spelling skill to a greater extent than no teaching (e.g., Devonshire & Fluck, 2010; Lyster, 2002; Manolitsis, 2017; Nunes, Bryant, & Olsson, 2003; for reviews, see Bowers, Kirby, & Deacon, 2010; Carlisle, 2010; Nagy, Carlisle, & Goodwin, 2013; Reed, 2008). Formal rules cannot be taught in isolation, but interventions teaching formal rules alongside grapheme–phoneme correspondences have been shown to aid spelling (for a review, see Squires & Wolter, 2016). Interventions involve the intentional selection by teachers or researchers of exemplars related to target rules and feedback, which have been found to be effective in promoting learning (Aslan & B  uml, 2016; Lo, Anderson, & Bunch-Crump, 2017). Teaching can be *explicit*, defined by the verbal enunciation of the rule; or *implicit*, exposure to the same materials without any reference to rules (Burgess & Etherington, 2002; Nunes & Bryant, 2006; Reber, 1976; Scott, 1990). While intervention research and the curriculum (Department for Education [DfE], 2013) demonstrate the effectiveness of teaching the functional rules relating to phonemes explicitly, so far explicit and implicit teaching have been compared systematically in relation to only a few morphological rules.

Bryant et al. (2006) compared the impact of explicit, implicit, and mixed teaching of a functional rule about suffix morphemes on spelling. All three taught groups (mean age: 9.5 years) participated in two computerized games in which they had to spell or to correct the spelling of derivatives with *-ion* and *-ian* endings. Children were taught in pairs by a researcher and were encouraged to discuss their answers during the games. At the start, the explicit group were taught the rule: *-ian* is used in person words, whereas *-ion* is used in words that are not about people, even though the schwa vowels have the same sound

(i.e., /ə/). Before the second game, the mixed teaching group were asked why the words had different endings; as no child could describe the use of *-ion* and *-ian*, they were taught the rule explicitly. The implicit group never received an explanation. At post-test, the explicit group spelled suffixes more effectively than the mixed and the implicit groups, but all groups outperformed an unseen control group. Thus, all three groups benefited from the teaching, but explicit teaching of the morphological rule led to greater gains.

Kemper, Verhoeven, and Bosman (2012) evaluated the impact of explicit versus implicit teaching about the functional rule relating to the conservation of stem morphemes on children's spelling in Dutch. Stems were studied in the context of inflected rather than derived words because the base form is conserved in plural words in spite of changes in pronunciation (e.g., /t/ at the end of the stem *bond* /fɔnt/ [dog] changes to /d/ in the plural *bonden* /'fɔn.də(n)/ [dogs]). Children (mean age: 7 years) either received implicit teaching (through exposure to plural words conserving a stem without an explanation of the rule), or explicit teaching (through exposure to the same materials plus rule explanation). At post-test, the explicit group outperformed the implicit group, who did not differ significantly from an unseen control group. As children seem to master inflection before derivation in oral and spelling tasks (Berko, 1958; Breadmore & Carroll, 2016; Carlisle, 1988), it is important to investigate whether the benefit of explicit stem teaching applies to the spelling of derived words, particularly because derivational morphology is an open system so people can continue learning derived forms throughout adulthood, whereas inflections form a closed system (Klima, 1972). Thus, the potential impact of the rule of stem conservation in derived words on vocabulary and spelling is considerably larger.

The aim of the present study was to test the hypothesis that explicit morphological teaching about the functional rule of stem conservation in derived forms has a greater impact on spelling than implicit or no teaching. Even though there are more than 3,800 English derivatives that conserve a stem plus an *-ion* or *-ian* suffix (Wilson, 1987), children are not typically taught the rule that stem spellings remain the same when an *-ion* or *-ian* affix is added in spite of changes in sound in schools in England (DfE, 2013). A further prediction of the current study is that implicit teaching would have a greater effect on spelling than no teaching, in a similar way to Bryant et al.'s (2006) research on suffixes. Thus, it is expected that exposure to exemplars of the stem rule could alone lead to improvements in children's spelling.

Method

Participants

Participants were 90 children (43 girls, 47 boys) in Years 3 (age range = 90–101 months; $M = 95$ months; $SD = 3.56$ months) and 4 (age range = 102–113 months; $M = 107$ months; $SD = 3.57$ months) from three state-supported primary schools in Hampshire and Oxfordshire. Seven- to 9-year-olds were recruited because previous research has reported positive effects for teaching morphemes in this age group (e.g., Bryant et al. 2006; Devonshire & Fluck, 2010; Kemper et al. 2012). The sample was ethnically diverse, including a range of socio-economic backgrounds. All children spoke English fluently: 11 had English as an additional language and nine had a recognized learning difficulty to increase generalization to mainstream classrooms. The study was conducted in the middle of the school year when no other interventions were offered to the participants. Ethical approval was granted by a research ethics committee; parental consent and children's active assent to participation were obtained.

Design

The design was a randomized controlled trial with assignment at the child level within each class; identical pre- and two post-intervention tests were included. There were three groups: an explicit group ($n = 30$), an implicit group ($n = 30$), and an unseen control group ($n = 30$). The pre- and post-tests were delivered to all three groups in the same class at the same time to avoid the risk of experimenter bias. After the pre-test, the explicit and implicit groups received a morphological intervention, whereas the unseen control group did not receive any teaching from the researcher. The delayed post-test was given two weeks after the intervention to assess impact stability. After the study had concluded, all children participated in a whole class session about morphology and spelling to extend possible benefits to all participants.

Measures

The pre- and post-tests were completed individually and administered on a whole-class basis by the researcher, a native English speaker of a Southern dialect. The test was developed drawing on morpheme spelling assessments by Nunes and Bryant (2006) and Wright (2013). Spelling performance was measured in transfer words, which were not included in the training, and pseudo-words; thus, the test was not a measure of recall of taught materials but of the ability to apply the rule to unknown stimuli. In the task, children were presented with 24 written sentences that contained a missing word (12 items) or pseudo-word (12 items), which they were asked to spell (see Table 1). The researcher read aloud each missing word in isolation, then within the sentence context, and finally, the target word was repeated. For example, they heard the word *musician* /mju(:)'zɪʃən/, then the sentence 'The man who plays the piano is a musician', then the word *musician* again, and they were given time to spell the word *musician* on an answer sheet.

All the words and pseudo-words were derivatives that contained a stem plus *-ion* or *-ian*. The stems in the pre- and post-test had different consonant endings in the base form (*t*, *ss*, *c*, or *y* [one *y* to *i* vowel change pair: *library*–*librarian*]) which were preserved in the derivatives in spite of phonological changes. The words were selected from the Children's Printed Word Database (Masterson, Stuart, Dixon, & Lovejoy, 2003) and the MRC Psycholinguistic Database (Wilson, 1987). Mean word frequency was assessed using the Subtlex-UK frequency database ($M = 3.83$; $SD = 0.77$) (van Heuven, Mandera, Keuleers, & Brysbaert, 2014).

Pseudo-word derivatives (e.g., *donician* /dɒ'nɪʃən/) were included in the tests; children were provided with a related pseudo-word stem prime (e.g., *donic* /'dɒnɪk/) in each written sentence because they would have had no way of knowing the stem spelling if they only heard the derived form (see Table 1). Each stem prime ended in a consonant (e.g., /k/ in *donic*), which was pronounced differently in the derived form (/ʃ/, i.e., *sh*) even though the spelling was conserved. Each pseudo-word derivative was composed of a made-up stem plus a real suffix. The use of unfamiliar stems eliminated the possibility that children were recalling the derived word spellings by rote and tested for rule learning. Pseudo-words were created using a similar approach to previous research (e.g., Bryant et al. 2006; Kemper et al. 2012; Rosa & Nunes, 2008): Real words were altered in a manner that preserved the syllable structure (e.g., *inj* in *injection* was replaced with *end*, generating the pseudo-word *endection*). In line with Kemper et al. (2012), spellings were marked as correct if the final consonant in the stem was spelled correctly in each

Table 1. List of sentences in the pre-test and post-test**Words**

1. The man who plays the piano is a musician /mju(:)'zi:fən/.
2. The girl was afraid to have the injection /ɪn'ɔ:ʃən/.
3. The electrician /ɪlek'trɪʃən/ fixed the lights.
4. The girl made a good impression /ɪm'pre:fən/ to her teacher.
5. The body-guard gave the children protection /prə'tek:fən/.
6. The librarian checked out the books /laɪ'breəriən/.*
7. She works in a hospital as a clinician /kli'nɪʃən/.
8. The boy had a cheerful expression /ɪks'pre:fən/.
9. He won the vote to be the next politician /pəli'tɪʃən/.
10. The woman had a good education /ˌɛdju(:)'keɪʃən/.
11. The statistician /stætɪs'tɪʃən/ solved a maths problem.
12. The man took possession /pə'ze:fən/ of a boat.

Pseudo-words

1. Someone who does lagic is a lagician /lædʒɪʃən/.
2. They had to ascuss the problem in an ascussion /əs'kʌʃən/.
3. The woman works in a donic as a donician /dɒ'nɪʃən/.
4. The police had to frotect the children by giving them frotection /frə'tek:fən/.
5. If you endect something it gets an endection /ɛndek:fən/.
6. My sister is good at trusic because she is a trusician /trju(:)'zi:fən/.
7. If you often trocess you develop a trocession /trə'se:fən/.
8. The man works in a koptic as a koptician /kɒp'tɪʃən/.
9. An expert at working out latistic problems is a latistician /lætɪs'tɪʃən/.
10. She had to delect her favourite sweets from the delection /di'lek:fən/.
11. To oexpress happiness you show a positive oexpression /ɒks'pre:fən/.
12. He is studying golitic to become a golitian /'gɒli'tɪʃən/.

Note.. The 6th sentence* for words was excluded from the main analyses because librarian is the only item to assess the y to i vowel change extension of the stem rule.

derivative; in the pseudo-words, the spelling was correct if the final consonant was the same as in the prime. No other parts of the words or pseudo-words were considered.

Interventions

Children in both taught groups were seen on a one-to-one basis by the researcher outside the classroom. The intervention session lasted approximately 35 min and included two parts: a teaching session and a practice game. All materials were designed by the first author. The control group were a business as usual group and did not work with the researcher.

In the teaching session, both taught groups were presented with slides on a computer screen. Each slide displayed word stems (e.g., *magic*), and the children were asked how they thought derivatives (e.g., *magician*) should be spelled. They were then shown the correct spellings. The explicit group were encouraged to search for similarities between the words; irrespective of the answer, they were taught that an easy way to spell words like *magician* is to think whether that word is related in meaning to another smaller one, like *magic*, which is contained within it. They were taught that these smaller words are stems whose spelling remains the same when an affix (e.g., *-ian*) is added, in spite of changes in sound. They were also taught that when stems end in *e* or *y* the last letter must

be removed before adding the suffix (see Ganske, 2008; Nunes & Bryant, 2009). In some sense, this models classroom practice, where children are often given an initial explanation about the content of the lesson and then proceed to work through examples on their own. The implicit group did not receive the explicit teaching. They were exposed to the same examples, but were not taught the stem conservation rule nor asked to provide explanations. Although the explicit group were taught the *e* or *y* to *i* vowel change in pairs such as *history*–*historian* and *celebrate*–*celebration*, this is not analysed in the current study because only one transfer word was used at post-test (see Table 1, 6th sentence). Any other complications of the stem rule relating to etymology (i.e., when the final stem consonant in the derived form is pronounced as /ʒ/ e.g., *conclude*–*conclusion*) were not included in the teaching.

Both intervention groups were then presented with the same computer-based practice game designed using MATLAB, which involved written and oral presentation of 30 sentence trials delivered in a random order to each participant. In each trial, children were asked to spell a whole word derivative (see Appendix 1), which was presented orally but missing from the written presentation, using a child-friendly keyboard with colourful and easily identifiable letters. Berninger, Abbott, Augsburger, and Garcia (2009) found that 6- to 11-year-olds are equally accurate at spelling using a keyboard or a pen; spelling using computers is perceived as more enjoyable and engaging (Lo et al. 2017; Torgerson & Elbourne, 2002). In line with previous interventions, feedback by presentation of the correct answer on the screen was provided (Bryant et al. 2006; Kemper et al. 2012). To avoid fatigue or boredom, if a child reached 15 correct spellings, the game ended. The probability of spelling 15 or more words correctly by chance out of 30 is less than 5% in a binomial model (number of trials = 30, success probability per trial = ≤ 0.33). Such a model reflects that if a child is guessing the spellings rather than using the stem rule they could spell at most one out of three answers correctly because there were at least three possible correct spellings of the final stem consonant (*t* [11 words], *ss* [7 words], and *c* [6 words], see Appendix 1). As there were more than three correct answer options through the inclusion of an additional category (i.e., spellings following the *e* or *y* to *i* vowel change [6 words], see Appendix 1) this reduced the likelihood of children reaching 15 or more correct spellings by chance even further (i.e., to less than 1%). No item used in the practice game was included in the post-tests.

Results

The analysis of the results considered the children's performance on the pre- and post-test spelling measure. The children's accuracy in the practice game part of the intervention was not analysed because the game formed part of the training and it has been argued that even if children perform well in training tasks, they often struggle when post-tested on non-trained transfer items afterwards (e.g., Kemper et al. 2012; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). Also there was incomplete data from the game due to the use of a criterion: In total, 90% of the children in the explicit group reached the criterion compared with only 37% of the implicit group; the difference in percentages is statistically significant: $\chi^2(1) = 18.37, p < .001$. Children who did not meet the criterion participated in a second, final run of the game. All of the children in the explicit condition compared with only 43% of the implicit condition met the criterion over the two runs of the practice game: $\chi^2(1) = 23.72, p < .001$. Thus, the non-trained post-test was used as the outcome measure in this study.

The first step in the analysis was to assess the pre- and post-test measure's internal consistency and the children's pre-test performance. As the *e* or *y* to *i* vowel change is not analysed in the study, the word *librarian* was excluded from the analyses (see Table 1). Cronbach's alpha was equal to 0.80 at pre-test, 0.80 at immediate post-test, and 0.82 at delayed post-test for words; for pseudo-words, the indices were 0.82, 0.88, and 0.89 (values above 0.7 are acceptable: Kline, 1999). Children's mean correct spelling scores by group and by testing occasion are presented in Figures 1 and 2. At pre-test, the children only spelled just above 25% of the spellings correctly across groups. The difference between correct spelling of the final stem consonant in words ($M = 27\%$, $SD = 24\%$) versus pseudo-words ($M = 26\%$, $SD = 24\%$) was small and not significant statistically ($t(89) = 0.43$, $p = .671$), which suggests that recalling specific word spellings by rote played little part in the spelling of derivatives. At post-test, the means were noticeably higher in the explicit group than in the implicit or control conditions; this effect was evident at both immediate and delayed post-test. The control group's post-test means did not increase over time. This shows that repeated exposure to the same test on three separate occasions did not by itself produce an improvement in scores. This indicates that any effects were due to the intervention rather than the testing (for testing effects, see Bouwmeester & Verkoeijen, 2011; Pan, Pashler, Potter, & Rickard, 2015; Pan & Rickard, 2018). The number of times the children's word and pseudo-word spellings changed from pre-test to post-intervention for each item and each group is presented in Appendix 2.

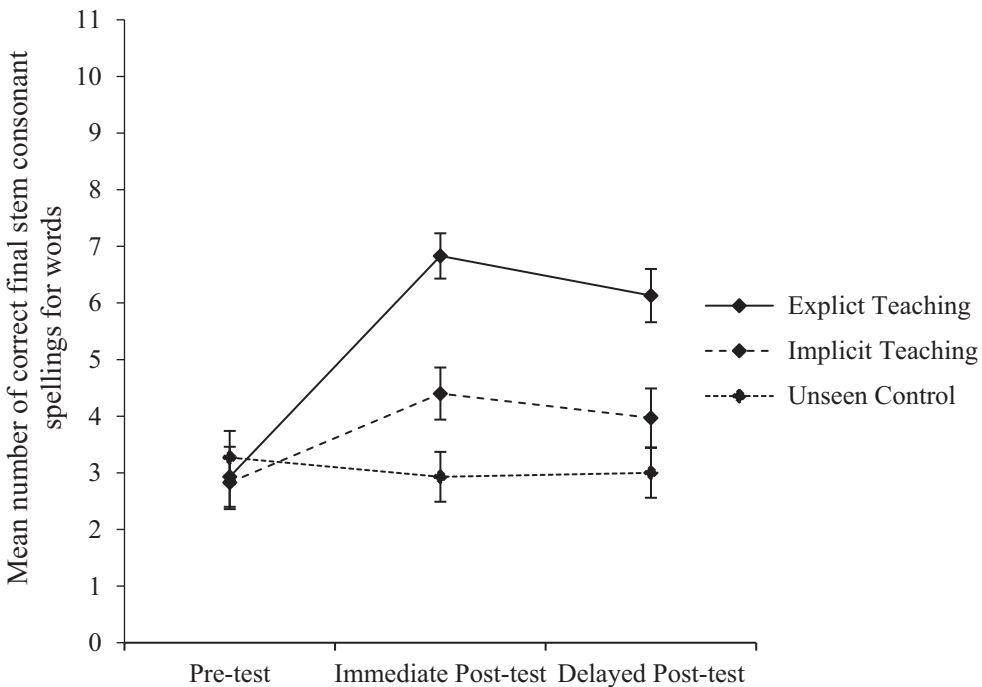


Figure 1. Mean number of correct final stem consonant spellings in real word derivatives (out of 11) for each experimental group ($n = 30$ per group) at pre-test, immediate post-test, and delayed post-test. Error bars represent one standard error from the mean. *Note.* The *y* to *i* vowel change derived word *librarian* has been excluded because only one transfer word was included at post-test (see Table 1, 6th sentence).

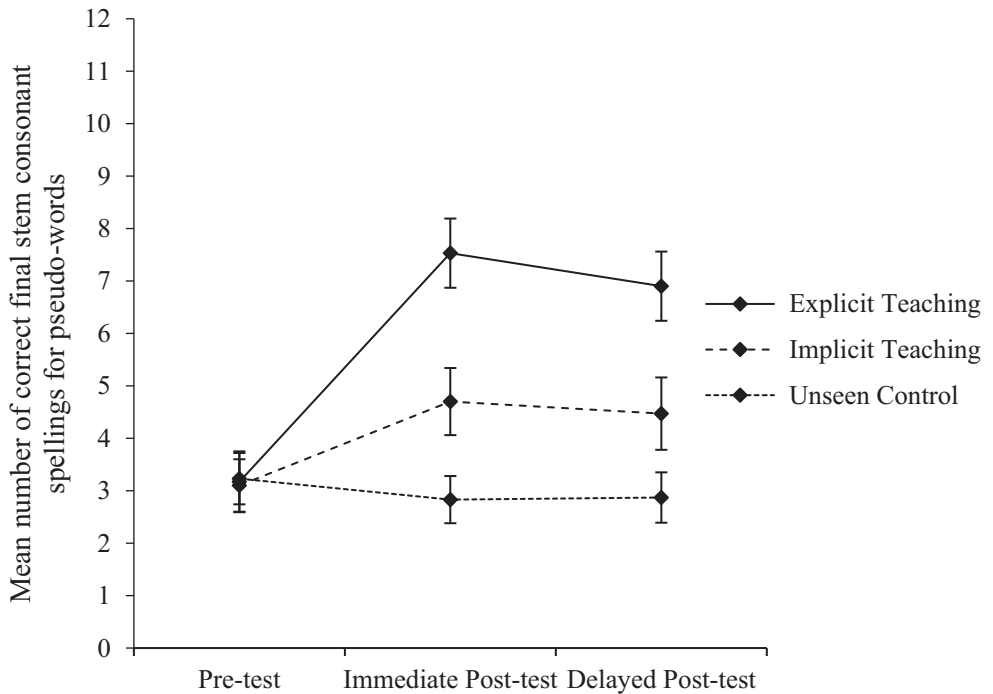


Figure 2. Mean number of correct final stem consonant spellings in pseudo-word derivatives (out of 12) for each experimental condition ($n = 30$ per group) at the three testing occasions. Error bars denote one standard error from the mean.

The second step in the analysis was to test the hypothesis that the explicit group would make more progress in spelling than the other two groups and that the implicit group would outperform the control group. Inspection of Figures 1 and 2 indicates that the pre-test means were similar across groups: The final stem consonant spelling scores did not differ significantly across the three groups for words, $F(2, 87) = 0.11, p = .899, \eta_p^2 = .00$, nor pseudo-words, $F(2, 87) = 0.02, p = .984, \eta_p^2 = .00$. The partial eta-squared (η_p^2) effect size estimates the amount of variance explained in the outcome measure by the treatment effects: At pre-test, group membership did not explain any variance in the scores, which indicates that the random assignment produced equivalent groups, even though the sample was relatively small. Thus, it was not necessary to control for the children's pre-test performance when analysing the impact of the interventions so mixed model analyses of variance were carried out.

To ascertain the effect of the intervention, two mixed analyses of variance were performed, one with word spelling and the other with pseudo-word spelling as the dependent variables. In both analyses, intervention group (a categorical variable with three factor levels: explicit, implicit, unseen control) was the between-participants factor and testing occasion (a second categorical variable with three factor levels: pre-test, immediate post-test, delayed post-test) was the within-participants factor. Mauchly's test indicated that the assumption of sphericity had been violated for words, ($\chi^2(2) = 7.02, p < .05$), but not pseudo-words, so the Greenhouse–Geisser correction was applied to the degrees of freedom in the analysis with word stem spellings as the dependent variable.

The statistical prediction for both analyses was that the interaction between group membership and testing occasion would be significant because the children's spelling scores did not differ between groups at pre-test, but they were expected to differ at post-test. There was a significant main effect of time on the children's word stem spelling, $F(1.86, 161.36) = 35.85$, $p < .001$, $\eta_p^2 = .29$, and on their pseudo-word spelling, $F(2, 174) = 26.43$, $p < .001$, $\eta_p^2 = .23$. This was superseded by a significant time x intervention group interaction effect for word, $F(3.71, 161.36) = 18.78$, $p < .001$, $\eta_p^2 = .30$, and pseudo-word stems, $F(4, 174) = 14.77$, $p < .001$, $\eta_p^2 = .25$. This indicates that the children's spelling scores between pre-test and the two post-tests differed across the experimental conditions. The effect sizes show that the proportion of the variance in the children's spelling scores that could not be attributed to other variables in the analysis but was explained by the interaction was large.

Post-hoc tests performed using the Bonferroni adjustment for multiple comparisons were used to compare the groups on both word and pseudo-word stem spelling at immediate and delayed post-test. Table 2 displays a summary of the results. The findings support the hypothesis that explicit teaching significantly improves children's stem spelling in derivatives in comparison to implicit or no teaching, but the hypothesis of a positive effect of implicit teaching compared to no teaching was not supported in the current study. The beneficial effect of explicit teaching was maintained over time. Cohen's d effect sizes capture the between-group differences and show that the difference between the explicit and control group means was larger than 1 pooled standard deviation across all comparisons. The effect sizes between the explicit and implicit groups were large to moderate, falling between 1 and 0.66 standard deviations.

Discussion

In line with previous research, the present study found that the morphological rule of stem conservation in derivatives is not evident for 7- to 9-year-old children. Explicit teaching of this functional rule was effective in improving children's spelling of transfer words and pseudo-words by comparison with an unseen control group and with an implicit teaching condition. This reinforces the positive effect of explicit teaching of

Table 2. *Post-hoc* comparisons for the children's word and pseudo-word spellings of the final stem consonant in derivatives between the three experimental groups on the two post-test occasions (Cohen's d in brackets)

	Words Immediate post-test	Delayed post-test	Pseudo-words Immediate post-test	Delayed post-test
Implicit teaching versus control group	$p = .056$	$p = .475$	$p = .085$	$p = .209$
Explicit teaching versus implicit teaching	$p < .001$ ($d = 1.04$)	$p < .05$ ($d = 0.79$)	$p < .05$ ($d = 0.79$)	$p < .05$ ($d = 0.66$)
Explicit teaching versus control group	$p < .001$ ($d = 1.71$)	$p < .001$ ($d = 1.25$)	$p < .001$ ($d = 1.54$)	$p < .001$ ($d = 1.30$)

Note. *Post-hoc* comparisons for the children's word and pseudo-word spellings of the final stem consonant in derivatives between the three experimental groups on the two post-test occasions (Cohen's d in brackets)

morphological rules previously documented in the literature (e.g., Bowers et al. 2010), extends Bryant et al.'s (2006) results on suffix spelling, and furthers Kemper et al.'s (2012) findings on stem conservation in inflected words in Dutch to stem conservation in derivatives in English. This extension is by no means trivial, as inflections are more easily mastered than derivations in both oral (Berko, 1958) and written language (Breadmore & Carroll, 2016; Carlisle, 1988), which could indicate differences in the underlying learning processes.

Contrary to the prediction, repeated exposure to word pairs selected to exemplify the stem conservation rule for the implicit teaching group was not found to improve children's spelling according to statistical significance tests in this study when compared to no teaching. Spelling improvement after mere exposure to words and pseudo-words in the literature has often pertained to the learning of specific spellings rather than rules (e.g., Gilbert, 1934; Ormrod, 1986; Pacton et al. 2014). However, some studies suggest that children may learn formal spelling rules implicitly: Children's sensitivity to permissibility in spelling has been demonstrated with pseudo-words in cultures where researchers thought it unlikely that the rules had been taught (e.g., Pacton et al. 2001). Furthermore, studies of spelling before school, such as those by Ferreiro and Teberosky (1983), Read (1971, 1986), and Treiman (1993), support the idea that at least some children learn the functions of graphemes in the absence of teaching.

It is intriguing that Bryant et al. (2006) found significant spelling improvements after implicit teaching of a functional rule relating to morphemes but a significant improvement was not found in this study nor in Kemper et al.'s (2012). The first possible reason is that *-ion* versus *-ian* is a simpler rule: 'if the word is an abstract noun use *-ion*; if the word is an agentive use *-ian*', whereas the stem conservation rule is more abstract as it refers back to the base form rather than predicting a specific spelling. A second reason is that the sample size in the present study was smaller than Bryant et al.'s (2006), and if the effect size of implicit teaching is smaller than that for explicit teaching, as is suggested by Bryant and colleagues, it may be that the current study lacked the necessary power to detect an effect of implicit teaching. Future studies could consider replicating this experiment with a larger number of participants. A third reason is that Bryant and colleagues employed two different games in the teaching: It has been argued that using variation in type of task can result in greater learning than teaching that uses a single task type (Marton, 2014). Future research on implicit teaching should consider the inclusion of different types of activity during interventions. A final explanation is that the implicit group in the current study were not encouraged to discuss the spellings in pairs, which was the case in Bryant et al. (2006). Even though no child arrived at a correct explanation without explicit teaching in their study, the children nevertheless improved their spelling of non-trained words and pseudo-words. As research on AG shows that children do benefit from implicit learning opportunities (see Ise et al. 2012; Samara & Caravolas, 2014; Steffler, 2014), more research on implicit teaching is needed for a comprehensive understanding of its possibilities and limitations.

Explicit stem teaching was assessed in two ways: sustainability over time and generalization to non-taught stimuli. The difference between the explicit group and the other two conditions was sustained after a two-week delay, and the effect size remained large in three of four comparisons. The children's spelling improved on transfer words that were not included in the teaching, and on pseudo-words, which shows that they were using a rule because they could not have known which consonants to use in the stem without using a clue from the pseudo-word base form. These results indicate that the knowledge acquired from explicit teaching is likely to enter long-term memory and can be

used in the spelling of non-trained words, as well as pseudo-words, which could not have been recalled word-specifically.

This study forms one of the first morphological interventions to employ MATLAB coding to develop and create a practice game for children to work through exemplars of spellings that follow a specific morphological rule. This reinforces the benefit of using computerized games to enhance spelling in the literature (i.e., Bryant et al. 2006; Lo et al. 2017; Nunes & Bryant, 2006) and advances previous work on teaching stems by Kemper et al. (2012) because children could actively type their answers to each trial using a keyboard rather than writing their answers by hand. As technological advancements have led literacy games and apps to form a focal part of a child's learning experience on a day-to-day basis, the practice games developed in this study are relevant and appropriate for teaching in school.

Finally, it is important to consider whether the one-to-one teaching could be effectively adapted for use in the large group setting of the classroom. A lesson could start with the teaching session used in this study by displaying stems and derivatives using PowerPoint and asking children to consider the connections in meaning and spelling between the words. This could then be followed by explicit teaching of the functional rule, and children could discuss a few examples in pairs. The games could be offered either by using a projector for class display of the game trials or within a school ICT suite, if a sufficient number of computers were available. Thus, future research could investigate whether adapting the teaching materials for use in the classroom shows a similar level of impact.

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Conflicts of interest

All authors declare no conflict of interest.

Author contributions

Lauren Burton, DPhil (Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review and editing). Terezinha Nunes (Conceptualization; Methodology; Supervision; Validation; Visualization; Writing – original draft; Writing – review and editing). Maria Evangelou (Conceptualization; Methodology; Supervision; Validation; Visualization; Writing – review and editing).

Data availability statement

The data are not publicly available due to privacy or ethical restrictions.

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Appendix I:

List of words in the practice game

Magician, discussion, infection, election, collection, logician, optician, procession, confession, celebration, selection, Egyptian, progression, obsession, mathematician, confusion, attraction, arithmetician, precision, Christian, subtraction, tension, comedian, historian, suggestion, physician, digression, compression, operation, perfection.

Table A1. Number of times the final stem consonant spelling changes for each item and each experimental group between pre-test and immediate post-test for words

		Final stem consonant score from pre-test to immediate post-test		
		Declined	No change	Improved
Musician	Explicit	0	14	16
	Implicit	0	22	8
	Control	3	26	1
Injection	Explicit	1	18	11
	Implicit	1	26	3
	Control	3	25	2
Electrician	Explicit	3	23	4
	Implicit	3	26	1
	Control	1	27	2
Impression	Explicit	0	13	17
	Implicit	4	16	10
	Control	2	25	3
Protection	Explicit	0	17	13
	Implicit	0	20	10
	Control	3	22	5
Clinician	Explicit	1	20	9
	Implicit	1	24	5
	Control	3	25	2
Expression	Explicit	0	13	17
	Implicit	4	18	8

Continued

Table A1. (Continued)

		Final stem consonant score from pre-test to immediate post-test		
Experimental group		Declined	No change	Improved
Politician	Control	5	25	0
	Explicit	0	23	7
	Implicit	2	24	4
Education	Control	0	30	0
	Explicit	0	14	16
	Implicit	2	22	6
Statistician	Control	4	23	3
	Explicit	1	23	6
	Implicit	0	27	3
Possession	Control	3	27	0
	Explicit	4	15	11
	Implicit	3	18	9
	Control	2	27	1

Note. The word *librarian* was excluded from the analysis.

Appendix 2:

Table A2. Number of times the final stem consonant spelling changes for each item and each experimental group between pre-test and immediate post-test for pseudo-words

		Final stem consonant score from pre-test to immediate post-test		
Experimental group		Declined	No change	Improved
Lagician	Explicit	1	14	15
	Implicit	2	20	8
	Control	3	24	3
Ascussion	Explicit	0	18	12
	Implicit	2	17	11
	Control	2	23	5
Donician	Explicit	1	15	14
	Implicit	1	21	8
	Control	2	27	1
Frotection	Explicit	0	18	12
	Implicit	6	17	7
	Control	2	23	5
Endection	Explicit	1	19	10
	Implicit	6	18	6
	Control	1	27	2
Trusician	Explicit	0	17	13
	Implicit	3	22	5

Continued

Table A2. (Continued)

		Final stem consonant score from pre-test to immediate post-test		
Experimental group		Declined	No change	Improved
Trocession	Control	5	25	0
	Explicit	1	20	9
	Implicit	6	12	12
Koptician	Control	6	20	4
	Explicit	0	18	12
	Implicit	3	22	5
Latistician	Control	2	27	1
	Explicit	1	17	12
	Implicit	3	22	5
Delection	Control	5	24	1
	Explicit	2	18	10
	Implicit	4	21	5
Oxpression	Control	6	22	2
	Explicit	0	17	13
	Implicit	2	16	12
Golitician	Control	2	27	1
	Explicit	2	20	8
	Implicit	4	20	6
	Control	4	23	3