HHS Public Access
Author manuscript
Educ Psychol. Author manuscript; available in PMC 2024 January 01.

Published in final edited form as:
Educ Psychol. 2023 ; 58(3): 130–145. doi:10.1080/00461520.2022.2108426.

A developmental perspective on feedback: How corrective feedback influences children's literacy, mathematics, and problem solving

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Abstract

Research in psychology and education indicates that corrective feedback can be a powerful learning tool. We provide a developmental perspective to focus specifically on how corrective feedback influences learning in childhood (~ages 3-11). Based on a systematic search, we review 44 empirical papers published between 1990 and 2022 examining the effects of corrective feedback on children's performance in the domains of literacy (*n*=18), mathematics (*n*=14), and problem solving (*n*=12). Across these domains, we synthesize research on how children respond to lessons and practice with, versus without, corrective feedback to provide theoretical and practical insights into (1) the effectiveness of corrective feedback in early childhood, (2) the features of effective feedback messages at different ages, and (3) the role of individual learner differences. We make several novel recommendations with some focused on future research questions and others focused on ways teachers can provide effective feedback to children.

Feedback is a critical component of the learning process, and there are numerous reviews on how feedback influences performance (Butler & Woodward, 2018; Kluger & DeNisi, 1996; Shute, 2008; Winstone et al., 2017). However, few reviews focus specifically on how feedback functions in childhood. Given that children are not just little adults – their minds, bodies, and environments are often qualitatively different from those of adults (e.g., Kuhn & Pease, 2006) – there is a need to better understand the effects of feedback on early learning. We offer a developmental perspective on the provision of corrective feedback on children's academic outcomes. Specifically, we outline three open questions about how feedback influences learning in childhood that focus on (1) the effectiveness of corrective feedback in childhood, (2) the features of effective feedback messages at different ages, and (3) the role of individual learner differences. Then, we report our findings from a systematic literature review where we identified 44 empirical papers that experimentally examined the effects of feedback on children's learning in the areas of literacy, mathematics, and problem solving. We synthesize this body of work to provide answers to our three questions and to

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develop a set of recommendations for future research and theory in this area and for the provision of feedback in learning contexts.

Task-Level Corrective Feedback

Feedback is essentially any information regarding someone's performance or understanding that is used as a basis for improvement. Though feedback can come in a variety of forms (e.g., grades, praise, hand-written comments), we focus on task-level corrective feedback that includes in-the-moment information about a specific response to a target problem (e.g., whether a child's solution to a math equation is correct; see Shute, 2008). This type of corrective feedback can facilitate knowledge change by signaling a gap between current and expected levels of performance, strengthening existing knowledge, and facilitating the identification and correction of errors (see Mory, 2004 for a review).

We recognize that feedback can be construed more broadly to incorporate fluid peer interactions and classroom discourse. We focus on task-level corrective feedback for both theoretical and practical reasons. Theoretically, it allows for a precise operationalization of feedback that avoids conflating the effects of relevant, but distinct learning processes and isolates the influences of feedback on student cognition. For example, reading a feedback message that contains the correct answer is different from being asked to self-explain why an answer is correct (e.g., Rittle-Johnson, 2006). Practically, task-level corrective feedback is pervasive in class conversations, on homework assignments, and in digital educational games (e.g., Hargreaves, 2012; Monteiro et al., 2019; Núñez et al., 2015; Schuldt, 2019). For example, in a study of students' perceptions of feedback, students characterized the majority of teacher feedback as descriptions of task-level performance (Harris et al., 2014), and one student's drawing of a course assignment epitomized this view by labeling the feedback components: "this shows that I got the answer correct"; "this tells me what I have done wrong" (p. 122).

Previous reviews have focused on task-level corrective feedback yet provide little insight into how it operates early in development. Meta-analyses in this area rarely include factors related to age or grade (e.g., Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Wisniewski et al., 2020), and those that do demonstrate a striking imbalance favoring adults. Kulik and Kulik (1988) reviewed 53 studies that varied the timing of corrective feedback, with 40 of those studies focusing solely on college students, and only eight including students below 8^{th} Grade. Similarly, a meta-analysis on the effects of feedback on computer-based learning reviewed 40 studies, only two of which included primary school children (Van der Kleij et al., 2015). As noted by Cáceres et al. (2021), "the evidence on how to design and implement feedback for students in primary school is scarce" (p. 11990). In this review, we synthesize the existing evidence in the feedback literature for preschool and elementary school students to inform theory on how feedback manifests for these students, what effects it might have, and why.

Theoretical Framework

To contextualize how we think about the function of corrective feedback, we outline a prominent Five-Stage Model of feedback processing originally introduced by Bangert-Drowns and colleagues (1991). We spotlight this model because it has been very influential in the feedback literature (see Shute, 2008), it is compatible with our operationalization of task-level corrective feedback, and it allows for interactions between the learner and the environment in ways that are consistent with developmental theory (e.g., Thelen, 2005; Vygotsky, 1978).

The Five-Stage Model depicts a cycle with different mental states of the learner (see Figure 1; Bangert-Drowns et al., 1991). Stage 1 is the learner's initial state, which includes individual differences in prior knowledge and interest. Then a question is posed and Stage 2 occurs, in which the learner engages in retrieval of existing information in memory. Stage 3 is the learner's response to the question and that response is associated with some level of confidence. Then feedback is provided and Stage 4 occurs, in which the learner evaluates their response in light of the feedback message. This step includes making sense of the feedback message, which depends on features of the feedback and the learner's expectations. Stage 5 represents the adjustments to knowledge, goals, and interests based on the feedback evaluation. Adjustments include strengthened or weakened retrieval pathways and high or low motivation to continue, and these adjustments help determine the next initial state (i.e., back to Stage 1).

This model highlights the multistep nature of the feedback process, the mindfulness of the learner, and the mutual influence between the learner and the environment – all of which are highlighted in developmental theories. For example, Vygotsky's (1978) zone of proximal development focuses on the role of external support and scaffolding, and it suggests that when children mindfully interact with feedback from a parent or instructor they can develop the skills and knowledge to solve the task independently. Similarly, a dynamic systems perspective focuses on how many related parts interact to produce behaviors within a given social, cognitive, and environmental context (Smith & Thelen, 2003; Thelen, 2005). These interacting parts certainly include the learner's knowledge and cognition, but they include perceptual, motor, and emotional processes as well (e.g., Grundmann et al., 2021). This perspective, in line with the feedback model, suggests learning from feedback unfolds within a multi-faceted system in which (a) brief in-the-moment experiences with feedback have the potential to create lasting, cascading adjustments over a longer time period, and (b) these changes or adjustments may not occur linearly, continuously, or every time but will depend on a confluence of factors for each learner on each task (Smith & Thelen, 2003; Thelen, 2005).

Considering this model from a developmental perspective can provide novel insights as our goal is not to test the Five-Stage Model directly, but to use it as a springboard for identifying open questions about how feedback functions in childhood. We believe this model provides an accurate foundation for *both* children and adults – the five proposed stages are relevant and ordered correctly. However, a developmental perspective may help reveal hidden assumptions or stages of the learning process and may allow us to consider how different stages may exert varying degrees of influence in childhood. Here we provide brief examples of how developmental shifts *may* play a role at each stage, and then we outline three open questions in the field that stem from these examples.

At Stage 1 and Stage 2, prior knowledge in the target domain has a central place as it helps form the initial learning state (Stage 1) and determines what information the learners can activate from long-term memory in response to a question (Stage 2). Prior knowledge in most academic domains accumulates as people get older and have more experience with the content, but gains and variability are large in early childhood. Consider that, on average, 2nd graders have a core vocabulary of about 5,000 words and 5th graders have about 8,000 words (i.e., gaining ~three new words each day), and there are large individual differences (e.g., Biemiller & Slonim, 2001). Thus, for children, it may be important to measure their prior knowledge of the task and expect it to influence learning from feedback to a high degree. At Stage 3 the learner provides a response to the question, and developmental shifts in the ability to evaluate one's knowledge may play a role. In general, young children tend to be overconfident in their knowledge – often predicting that they will remember more than they do or reporting high levels of certainty on incorrect responses (e.g., Lipko et al., 2009). This overconfidence in their initial response, which tends to decline with age (e.g., Shin et al., 2007), may influence children's propensity to seek out help or feedback or to accept feedback once it is provided (e.g., Nelson & Fyfe, 2019).

Stage 4 in the model is the evaluation of the feedback message, but this assumes that the learner has noticed the feedback, that it is in a form they can interpret, and that they view it as credible. These assumptions may not hold with children who are still building up expectations about what feedback is and how it is delivered (e.g., Heyman et al., 2013). For example, selective attention is a cognitive skill that helps direct attention toward task-relevant information and screen out irrelevant information; it undergoes marked development across age and may be particularly useful in guiding children's attention toward instructional feedback messages (e.g., Plebanek & Sloutsky, 2017; Smith & Kemler, 1977). Yet even older children with years of school experience have been shown to ignore instructional information, including feedback (e.g., Clarebout & Elen, 2008). In one study, researchers used eye tracking to examine 11-year-olds' perceptual processing of visual feedback in a digital learning game (Tärning et al., 2020). Of all the feedback instances, 33% were not even noticed by the children; and of those that were noticed, 39% were not read. Finally, Stage 5 represents the actual changes to knowledge and goals, which may depend on whether learners are motivated to use and incorporate the feedback information mindfully once they have noticed it and processed its meaning (Bangert-Drowns et al., 1991). This step may be especially difficult for younger, relative to older children, as they tend to discount negative feedback or indicate that it should not be used (e.g., "because it can hurt your feelings"; e.g., Marble et al., 2021).

These examples are not comprehensive and they do not imply that feedback processing will always operate differently in children and adults. Rather, these examples highlight the many open questions about children's learning from task-level corrective feedback and the factors that may influence it. We outline three of those questions here that motivated this literature review.

Three Open Research Questions

The first question is *whether corrective feedback has beneficial effects for preschool and elementary school students*. On the one hand, this question is about whether external, corrective feedback is always necessary, as some knowledge change can unfold as a result of practice alone and gaining familiarity with the task (e.g., Messer et al., 1996). On the other hand, this question is about whether young children are capable of learning from corrective feedback, especially given the required (and sometimes hidden) processes for evaluating the feedback in Stage 4 and using it to make adjustments in Stage 5 – *noticing* that feedback was provided (e.g., seeing the comments, hearing what was said), *decoding* the feedback message (e.g., being able to read the feedback, knowing if a check mark means correct), *relating* the feedback to the initial response (e.g., comparing the given response to the correct one), *integrating* this information with prior knowledge, *deciding* how to proceed, and *acting* on that decision (e.g., Kulhavy & Stock, 1989; Timms et al., 2016). Thus, one goal is to examine the literature for whether and when children can benefit from corrective feedback relative to practice without feedback.

The second question is *whether there are specific features of feedback that enhance its efficacy and whether these change with age*. Stages 4 and 5 in the model occur after feedback has been provided and depend on the type of information in the feedback message and how that interacts with the social and cognitive aspects of the learning context. Children have less cumulative experience with feedback than adults and may not have the same assumptions about how it is typically provided (e.g., when or where to look for it, how it is presented). Indeed, there can be marked differences between what a student interprets as feedback and what a teacher believes has taken place (e.g., Hattie & Yates, 2014). In part, these mismatches may stem from the fact that feedback can be provided across multiple modalities (e.g., written, verbal), at different times (e.g., immediate, delayed), from different sources (e.g., teacher, computer program), and include different types of information (e.g., hints, correct answers). Some of these variations in feedback may be more developmentally appropriate than others. For example, students in preschool through 3rd grade are typically still learning to read (Chall, 1983) and it may be difficult for them to benefit from written feedback. Thus, a second goal is to delineate the different features of effective feedback provided to children at different ages.

The third question is *whether the influence of effective feedback depends on individual learner characteristics in childhood*. Many researchers argue that characteristics of the learner can be as influential, if not more so, as characteristics of the feedback itself (e.g., Narciss & Huth, 2004), and a developmental approach indicates a need to consider these elements during childhood when many cognitive, perceptual, and emotional processes are still developing. There are a variety of characteristics that form the mental state of the learner at Stages 1, 2, and 3 in the model and that develop rapidly in early childhood – including prior knowledge, knowledge monitoring, and working memory. For example, working memory capacity tends to increase linearly with age (Gathercole et al., 2004), and even within a small age range working memory capacity can vary and influence how learners respond to various forms of feedback (e.g., Wardlow & Heyman, 2016). Thus, a third goal of this review is to identify whether the effects of feedback vary for children with different personal characteristics.

To provide answers to these questions, we conducted a systematic review of the literature that examines the effects of task-level corrective feedback on children's learning. We focused on literacy, mathematics, and problem solving. Literacy and mathematics form the critical content domains in early elementary school standards (NGACBP, 2010), and early skills in these two domains are associated with later academic achievement (e.g., Duncan et al., 2007; Watts et al., 2014). We also included problem solving in our search because many problem-solving tasks intended for young children tap into their executive function and self-regulation skills, which are linked with academic achievement (e.g., Rutherford et al., 2018). We synthesized the empirical work across these topics to provide theoretical and practical insights into (1) the effectiveness of corrective feedback in childhood, (2) the features of effective feedback messages at different ages, and (3) the role of individual learner differences on effective feedback in childhood.

Method

We used five primary criteria to systematically search the feedback literature and locate empirical papers on how feedback influences children's learning. To be considered, the report:

1. Included a sample of children who were in preschool to sixth grade (3 to 11 years old). This range captures the entire elementary school period, which is often considered to span from kindergarten to fifth grade. Because this school period can sometimes include the grade levels just before kindergarten (i.e., preschool) and just after fifth grade (i.e., sixth grade), we decided to include research in these grades as well.
2. Included a condition in which children received task-level corrective feedback and a control condition in which children completed similar activities but with no feedback. The feedback needed to be contingent on the child's response to a target task and provided by an instructor or an instructional device (e.g., digital game).
3. Used an experimental or quasi-experimental design to compare these conditions.
4. Included outcome measures related to literacy, mathematics, or problem-solving knowledge.
5. Was published in English as a peer-reviewed journal article between 1990 and 2022.

In early 2022, we searched three databases for relevant research that met these five criteria: Education Resources Information Center, PsycINFO, and Web of Science. Within each database, we (1) selected peer-reviewed journal articles, (2) selected English as the language, and (3) restricted the dates to 1990-2022. Then, we searched the database using three parameters. The paper needed to include the term feedback in the title or abstract, *and* the paper needed to include relevant topic information in the title or abstract, *and* the paper needed to include the terms “elementary or early childhood education or preschool or kindergarten” anywhere in the text. To determine relevant topic information for literacy we used the search terms “reading or writing or spelling or literacy,” for mathematics we used the search terms “math* or numeracy,” and for problem solving we used the search terms “problem solving or cognit*.”

The search produced 2,294 results. After removing duplicates, the search produced 1,658 unique entries. To determine whether these entries met the five criteria for inclusion, two members of the research team read the title and abstract of each paper and worked collaboratively to ensure consistency. Ultimately, 220 entries were included for further review. A third researcher independently coded a random 15% of the 1,658 unique entries (blind to the other researchers’ judgments), and agreement as to whether it should be included for further review was high (90%). Thus, the original coders’ decisions were deemed reliable.

The next step was to read the full papers of these 220 entries to determine which papers met all five inclusion criteria. Two members of the research team engaged in a two-phase procedure to ensure reliability of the coding. In the first phase, both researchers read the same 24 papers together (~10% of entries) to ensure appropriate implementation of the inclusion criteria and to discuss any disagreements. Next, both researchers read 20 papers independently (~10% of remaining entries) blind to each other’s’ judgments, and decisions about inclusion were consistent (90% agreement). One researcher then read all remaining papers to identify whether they met the five criteria. Of all 220 articles, 34 were deemed eligible for inclusion in the final review. Many papers were excluded because they lacked a true control group with no feedback or because the sample included participants outside the pre-specified age range. The final step was to employ a snowball method in which the research team examined the reference sections of the 34 papers as well as other papers from the authors of these articles. This process resulted in 10 additional papers that met our five criteria. The final set of 44 papers (which included 59 unique experiments) represents the basis of our analysis.

For each paper, we extracted relevant information about the sample, the research context, and the features of the feedback provided to participants. For this latter category, we coded information related to the feedback content, feedback modality, feedback timing, and feedback source. Two researchers independently coded these features in all 44 papers, discussed minimal discrepancies, and reached consensus. Information for how these four feedback features were defined and coded across all 44 papers is reported in the supplemental material (see Table S1). We also extracted information about individual learner differences and whether they were examined as potential moderators of the effects of feedback on children’s learning outcomes.

Findings

This section presents the findings of the search and has five sections. In the first section we provide descriptions of the sample and study characteristics across all papers, and in the second section we provide a narrative summary of the major programs of research within each topic. The next three sections include our synthesis of the findings related to our three questions that focus on (1) the effectiveness of corrective feedback in childhood, (2) the features of effective feedback messages at different ages, and (3) the role of individual learner differences.

Section 1: Summary Information Across All Papers

All 44 papers were published between 1990 and 2022, but most were published within the last 10 years (n = 32/44, 73%). In terms of sample characteristics, just over half of the papers included samples from the United States (n = 24/44) and almost a quarter included samples from the Netherlands (n = 10/44). The remaining 10 papers included samples from Canada (n = 3), Germany (n = 2), Taiwan (n = 2), France (n = 1), Switzerland (n = 1), and the UK (n = 1). Across papers, sample sizes varied from 10 to 1808 (*Median* = 62), and after removing two outliers, the average sample size was 83. We categorized the samples within the papers into four bins based on the average age of participating children: 34% of papers focused on 3- to 5-year-olds, 20% focused on 6- to 7-year-olds, 34% focused on 8- to 9-year-olds, and 11% focused on 10- to 11-year-olds[1]. Only two papers focused on children with learning disabilities.

In terms of the research context and materials, most of this research was conducted in a school setting (n = 37/44, 84%) though implementation varied in terms of one-on-one or group sessions. Just over half of the papers reported using a computer or tablet for task administration (n = 24/44), and the other papers reported using physical materials (e.g., paper/pencil, objects, cards). Length of training was typically one session (*Median* = 1) though it ranged from one session to 20 weeks (*Mean* = 6.3 sessions). Almost all papers included an outcome measure assessing task performance (i.e., ongoing accuracy on the training task on which feedback is provided) or immediate posttest performance (i.e., accuracy on a similar task occurring within a day of training). About half (n = 20/44) included a measure of maintenance (i.e., accuracy on a similar task several days to months later), and only eight papers (18%) included measures of transfer to untrained tasks.

In terms of feedback features, there was large variability. Across the 44 papers, there were 60 unique feedback conditions because some papers reported a single experiment with multiple feedback conditions. Table 1 displays the frequency of each feature; it was common for feedback to include an explicit verification judgment (e.g., that answer is right/wrong) (85%) and the correct answer (67%), to be provided in spoken words (60%), to be given immediately after each item (87%), and to be provided from a person (55%) and/or from a computer (50%).

Section 2: Narrative Overview Within Each Topic

Our examination of the 44 papers revealed that the literature on children's learning from feedback is disjointed with different programs of research focusing on different ages,

[1]Several papers focused on children spanning multiple age ranges. Typically this resulted from studying children in a single grade (e.g., studying a 2nd grade classroom with mostly 7-year-olds and a few 8-year-olds). Details for each study are in Figures 2, 3 and 4. One paper (Stevenson et al., 2017) included children from all age bins (from age 4.9 to 11.3) as the researchers combined data from six separate studies using age-appropriate analogy tasks.

feedback types, and methodological designs. Given the fragmentary nature of the literature, we use this section to summarize key programs of research within each topic.

Literacy Skills.—Our search identified 18 papers on children's literacy skills (see Figure 2), which focused on skill-building interventions in school settings with children ages four to nine. These papers fit within one of three research programs. The first subset of papers reported studies on how feedback influenced writing fluency in 3rd- and 4th-grade children (Hier & Eckert, 2014, 2016; Hier et al., 2019; Koenig et al., 2016; Nobel & Grünke, 2020; Truckenmiller et al., 2014). These studies investigated a multi-week, class wide writing intervention. Each week, students were given a story prompt and practiced writing a narrative, and then received performance-based feedback indicating the number of words they had written and whether this amount increased or decreased relative to prior attempts. The second subset of papers reported studies on how feedback influenced 1st- and 2nd-graders' ability to practice reading individual words (Martin-Chang, 2017; Martin-Chang et al., 2017; Spaai et al., 1991; Van Gorp et al., 2017). These papers offered competing hypotheses as to why feedback may either benefit children's reading or instead hinder "self-teaching" via uninterrupted practice. The third subset of papers investigated feedback that was incorporated into educational technology, often focused on using automated features of the program to incorporate prompts or provide multiple attempts to reach the correct answer (Bonneton-Botté et al., 2020; Kao et al., 2016; Kegel & Bus, 2012; Kegel et al., 2011; Muis et al., 2015; Patchan & Puranik, 2016).

Mathematics Skills.—Our search identified 14 papers on children's mathematics skills (see Figure 3), which focused on comparing different types of feedback and on making theoretical claims about children's cognition (e.g., whether strategy change is abrupt). Most were conducted one-on-one in a school setting, focused on children ages seven to nine, and fit within one of three subsets of research. The first subset of papers examined how the timing of feedback influenced arithmetic skills for children with mathematics learning disabilities (Brosvic et al., 2006; Dihoff et al., 2005). These researchers evaluated the Immediate Feedback Assessment Technique (IF-AT), which is a scratch-off scantron sheet that allowed students to get immediate feedback on the accuracy of their answer and multiple chances to uncover the correct answer. The second subset of papers represented research on embedding feedback in digital platforms, with several studies that emphasized the potential benefits of practice without feedback (Fyfe, 2016; Messer et al., 1996) and others that tested the efficacy of a specific tablet app or program (Faber et al., 2017; Fazio et al., 2016). A third subset of papers investigated how feedback influenced children's understanding of mathematical equality, with emphases on the generation of new strategies and the moderating role of children's prior knowledge (Alibali, 1999; Brown & Alibali, 2018; Fyfe et al., 2012; Fyfe & Rittle-Johnson, 2016a, 2016b, 2017).

Problem-Solving Skills.—Our search identified 12 papers on children's problem-solving skills (see Figure 4), which examined whether feedback directed children's attention to specific features of the problem in a way that enhanced cognitive change. The papers focused on children ages three to six in controlled, one-on-one settings and included one of three tasks. One set of papers reported research using the Dimensional Change Card

Sort task, where children sorted a set of cards using one rule (e.g., by color) and then had to switch and sort using a new rule (e.g., by shape) (Bohlmann & Fenson, 2005; Espinet et al., 2013; Tarullo et al., 2018; van Bers et al., 2014; van Bers et al., 2020). These studies investigated whether demonstrations from an experimenter or salient feedback from a computer influenced children's learning of the rules. A second set of papers examined relational reasoning skills using tasks in which children chose a target option that shared relational, rather than superficial, commonalities with a source object (Chen et al., 2016; Chiu & Alexander, 2014; Honomichl & Chen, 2006; Stevenson, 2017; Touw et al., 2020). These studies focused on children's explanations of their responses and whether feedback helped children attend to the problem structure. The remaining two papers used the Balance Beam task, where children made predictions about the movement of a balance beam with different configurations of weights (Tudge & Winterhoff, 1993; Tudge et al., 1996). These studies focused on whether physical feedback (i.e.., the movement of the beam) and peer collaboration influenced children's knowledge gains.

Section 3: The Beneficial Effects of Corrective Feedback for Children

Overall, corrective feedback was largely effective in promoting children's literacy, mathematics, and problem-solving outcomes relative to practice without feedback. Across all 44 papers, 41 (93%) reported at least one positive effect of feedback on measures of learning and performance. Only three papers (Hier et al., 2019; Messer et al., 1996; Patchan & Puranik, 2016) exclusively reported no benefits of feedback compared to the no-feedback control condition. The beneficial effects of feedback were pervasive across topics and most prevalent on measures of performance during training or on an immediate posttest. Across all three topics, it was extremely common for the researchers to highlight "the effectiveness of feedback" (Dihoff et al., 2005, p. 63) and how "feedback significantly increased the effect" of training (Duhon et al., 2015, p. 83). One research group found benefits of feedback for 5- to 6-year-olds and noted: "We find this particularly noteworthy and important from a theoretical perspective, given that researchers have previously assumed that children at this age do not have the skills necessary to regulate such feedback" (Muis et al., 2015, p. 7). Thus, the results are quite promising as corrective feedback can be used effectively by children ages three to 11 suggesting theories of feedback should incorporate the positive effects of corrective feedback across a greater range of the lifespan.

Despite the emphasis on the benefits of feedback, there were certainly mixed effects and nuances regarding the way feedback conditions were analyzed and compared. In fact, 25 of the 44 papers (57%) reported at least one neutral or negative effect of feedback relative to the no-feedback condition. Though corrective feedback often improved performance on the training activities, the knowledge gained from feedback did not consistently transfer to other outcome measures (e.g., from reading to spelling; Martin-Chang et al., 2017, from procedures to concepts; Fyfe et al., 2012), nor was it always maintained over time (e.g., two to six weeks after training; Hier & Eckert, 2014). This led some researchers to note that "the effects of feedback are contextual and transient" (Bohlman & Fenson, 2005, p. 130). There were some instances of feedback supporting maintenance over time, and these were often in studies that included multiple training sessions and/or scaffolded one-on-one support from the experimenter. These variable effects of feedback on maintenance suggest the descriptive aspects of theory on feedback need to be elaborated to consider the tasks, topics, and contexts in which feedback is implemented. For example, one group concluded "performance feedback not only is effective but may also be a necessary component" of elementary school writing interventions (Koenig et al., 2016, p. 289), whereas another group using a computer program warned others to "not always assume that feedback and explanations given by a computer will be the… best way to improve performance" (Messer et al., 1996, p. 295).

As far as differences across the age groups, there was no overarching pattern suggesting feedback effects get stronger or more positive with age. Instead, positive effects of feedback were reported in children spanning the entire age range of three to 11. In fact, the most consistent beneficial effects were reported in the papers on problem solving, which tended to focus on younger children ages three to six. These benefits were likely due to the highly structured nature of these problem-solving experiments, which were conducted one-on-one with an experimenter providing targeted feedback that contained multiple types of information across multiple modalities. These structured settings may have helped hone children's selective attention abilities and foster learning. For example, in Tarullo et al. (2018), preschool-aged children enhanced their accuracy on a problem-solving task by using highly salient, trial-by-trial feedback in one condition of the task. The researchers noted that "stickers appeared on the screen after correct trials and vanished after incorrect trials, so the link between performance and reward was emphasized on every trial. This approach may have served to scaffold self-monitoring and maintain motivation and attention" (Tarullo et al., 2018, p. 174).

Section 4: Effective Features of Corrective Feedback at Different Ages

Considering that almost all papers reported at least one positive effect of feedback, we looked across each unique feedback condition to identify features of the feedback that may be most effective (see Table 1). Across the 44 papers, there were 60 unique feedback conditions that were examined and compared to a no-feedback condition. For each feedback condition, our goal was to extract information about the feedback content, modality, source, and timing.

In terms of *content*, it was typical across ages for the feedback to include a verification judgment and to supplement this with the correct answer or, more rarely, with multiple attempts. The inclusion of information beyond the correct answer – gradual prompts leading up to the answer or explanations of the correct answer – was not common; however, seven of the 10 conditions with this feature were in the two younger age groups (ages three to seven) and the frequency of these kinds of prompts decreased across all four age groups with none present for children ages 10 and 11. This pattern suggests a trend for researchers to provide more scaffolding in the feedback content prior to age eight.

In terms of *modality*, feedback in the form of spoken words and visual symbols was fairly common across ages. However, several features differed by age. Even though visual symbols were present at various ages, the type of visual symbol was often simplistic for younger children (e.g., check marks) and included more complex graphical representations for older children. Two modalities - audio feedback signals (e.g., ascending tones) and physical feedback demonstrations - were only reported in papers with younger samples (ages three to seven). Together, these three trends suggest that corrective feedback for younger children is often made more perceptually salient. Also, feedback in the form of written words (e.g., “You are right!”) was only provided for children ages eight and older. This finding is consistent with a trend related to the *source* of feedback. Though feedback from a person or computer was very common across the full age span, feedback provided on a piece of paper (e.g., packet of work) was only provided for children ages eight and older and it was most common in the oldest group (ages 10 to 11).

In terms of *timing*, the feedback conditions included in this review did not vary much, as most conditions included immediate feedback after each trial or attempt. Seven of the eight feedback conditions with delayed feedback focused on the two older groups (ages eight to 11), but it is not clear that this form of feedback was beneficial. Illustratively, several papers in the area of mathematics experimentally examined the timing of feedback and found that trial-by-trial immediate feedback was more helpful compared to delayed feedback for children ages eight to 11 (e.g., Brosvic et al., 2006; Dihoff et al., 2005; Fyfe & Rittle-Johnson, 2017). Thus, strong conclusions about the effects of feedback timing on child knowledge gains are unwarranted.

Our extraction of information from each feedback condition revealed one feedback feature we had not originally considered, which we refer to as *feedback alerts*. These alerts were frequently provided *before* the child responded to the task and served to let children know that they would be receiving feedback or to orient them to the type of information that would be provided. For example, in Spaai et al. (1991), children “were told whether and in what form spoken feedback would be provided,” and in Labuhn et al. (2010), “students in any feedback condition were shown the feedback graph and given a brief explanation in order to make sure that they understood how the graphing was supposed to work.” Feedback alerts were present in approximately half of all feedback conditions, and they were included in papers that spanned the full age range, but least frequently with the oldest group (ages 10 to 11). From a theoretical standpoint, these findings indicate a need for models of feedback processing to consider features of feedback that occur *before* the target task and their influence on student cognition.

Section 5: The Moderating Role of Individual Learner Characteristics

We looked within each of the 44 papers and identified whether individual learner differences were examined as potential *moderators* of feedback. The researchers had to have considered the variable at the individual student level, assessed it prior to training, and explored or speculated on how it would interact with feedback conditions. Variables that were used simply to describe the sample or were used only as covariates in statistical models were not included. Over half of all papers (n = 25/44, 57%) examined at least one individual difference in this way and 10 papers investigated more than one. Many papers considered how feedback depended on aspects of children’s prior knowledge (n = 14) or prior experience related to age or grade (n = 9). Other factors included gender (n = 6), working memory (n = 3), confidence (n = 2), inhibitory control (n = 1), and genetic make-up (n = 1). In 17 of the 25 papers, researchers found some evidence to suggest that learning from feedback depended on the child's characteristics, most predominantly on prior knowledge or on prior experience (e.g., time in school).

In the papers that considered prior knowledge, it was common (in 10 of the 14 papers) for children with low prior knowledge to benefit more from feedback relative to children with high prior knowledge. In some cases, almost all children benefitted from feedback, but children with low prior knowledge benefitted the most. For example, as Fazio et al. (2016) noted: "students with less initial knowledge showed greater improvements than peers with more initial knowledge" from playing the game with feedback (p. 10). In these papers, researchers explained the moderating effect as a ceiling or threshold effect, suggesting lower-knowledge children had more room to grow (e.g., Bonneton-Botté et al., 2020; Stevenson et al., 2017). In other cases, higher-knowledge children experienced negative effects of feedback. For example, van Gorp et al. (2017) found that experienced readers benefitted most from no-feedback during training, which was not true of less experienced readers (see also Fyfe & Rittle-Johnson, 2012; 2016a; 2016b). In these papers, researchers speculated that feedback was interrupting high-knowledge children's internal processing in a way that made feedback less effective than practice alone.

There were a few cases that showed a somewhat opposite pattern with positive effects for children who were older or who had more experience. These papers primarily showed greater benefits of feedback for kindergarteners or first graders at the *end* of the year relative to the *beginning* of the year (Muis et al., 2015; Tudge & Winterhoff, 1993; Spaai et al., 1991). One research team speculated that "by the eighth month of the academic year, students' prior knowledge base was much richer, which may have provided them the opportunity to adjust their approaches to learning in the feedback condition" (Muis et al., 2015, p. 11). Together, these findings suggest that children need a sufficient amount of experience early in development to make sense of the task and feedback, but for most children the benefits of feedback may actually be stronger for those with lower prior knowledge of the task.

Discussion

Feedback plays a central role in children's learning experiences (Hattie & Timperley, 2007), but important nuances emerge when taking into account feedback features, individual differences, and developmental age. We have provided a developmental perspective and identified 44 papers between 1990 and 2022 that evaluated the provision of corrective feedback to children ages three to 11. We extracted information from each paper and gained practical and theoretical insights into the (1) the effectiveness of corrective feedback in childhood, (2) the features of effective feedback messages at different ages, and (3) the role of individual learner differences. Here, we briefly summarize the answers to our three questions, and then comment on the state of the field and offer recommendations for research and practice (Figures 5 and 6).

The Effectiveness of Corrective Feedback

Our synthesis revealed that young children can, and often do, benefit from basic corrective feedback on task-level performance. This result is consistent with research on adults that often demonstrates positive effects of feedback for learning outcomes (e.g., Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Van der Kleij et al., 2015). In the research surveyed here, it was common for children, regardless of age or topic area, to use the information in the feedback message to improve their performance on the target task more so than children who practiced the same task without feedback. These studies often focused on typically-developing children in preschool to Grade 6 who engaged in one-on-one training sessions at school, though the context and training features varied greatly across studies and often depended on whether children were learning to read, solving mathematics problems, or reasoning about rules.

However, also consistent with the broader literature (see Wisniewski et al., 2020), the effects of feedback on children's learning were quite variable, with over half the papers reporting neutral or negative effects of feedback. This means there were a substantial number of cases in which children who practiced without feedback did just as well *or better* than students who practiced with feedback. The papers surveyed here often indicated neutral or negative feedback effects on measures of maintenance or transfer. Getting students to transfer knowledge across problems and time is a persistent dilemma in education (Lobato, 2006), and it suggests that additional support may be needed after training with feedback. There were also some neutral effects of feedback for ongoing task performance; these effects demonstrate the need to include no-feedback control conditions to test intuitive assumptions that feedback generally helps (see Messer et al., 1996), and to consider why the feedback may not always be beneficial. For example, did the children not notice it, not understand it, or not want to use it? These effects have implications for theory as they suggest that updated models of feedback processing should break Stage 4 into more nuanced steps (e.g., notice, decode, evaluate, act upon; see Tärning et al., 2020 and Timms et al., 2016). Demarcating these steps may help pinpoint the reasons for the neutral and negative effects of feedback, and can motivate future research on attention to feedback in both children and adults, given developmental differences in selective attention (e.g., Plebanek & Sloutskey, 2017). In fact, it was rare for the surveyed studies to focus on in-the-moment processing as it relates to factors that vary with age – such as attention, confidence, or avoidance of feedback – and future research could help fill this gap.

The Features of Effective Feedback Messages

The corrective feedback provided in these studies varied in content, modality, timing, and source. Our synthesis of features pointed to several effective features of feedback for children ages three to 11. Across these ages, effective feedback conditions included content that went beyond mere verification (see Shute, 2008). That is, in addition to simple judgments (e.g., right/wrong, better/worse), the feedback often contained the correct response and sometimes provided children with additional attempts to solve the same problem. Also, feedback at these ages was predominantly provided in a spoken and/or simple visual format from either a person or computer (e.g., checkmark when correct) and given immediately after each problem or task.

However, there were stark trends suggesting a potential need to tailor feedback features based on age. For younger children (ages three to seven), feedback content was sometimes supplemented with additional prompts to guide students to the correct answer or with explanations of the correct answer. Further, the feedback message was made perceptually salient with audio information (e.g., ascending tone for correct answer) or physical components (e.g., observing a researcher manually re-sort a card into the correct stack). In contrast, written feedback and other feedback provided on paper (e.g., charts, scantrons) were only provided for older children (ages eight to 11), and alerts to future feedback were scaled back in samples with the oldest children (ages 10 to 11).

Strong recommendations on tailoring feedback across development are difficult to form due to the disconnected nature of the literature. Certain features of feedback were sometimes studied in one age group but not another. Notably, scaffolded feedback features including prompts/explanations, audio symbols, and physical demonstrations were rarely or never studied in older children ages eight to 11. It is possible that these scaffolds are no longer necessary at these ages, but even adults sometimes benefit from additional explanation (e.g., Butler et al., 2013). Further, strong recommendations on the timing of feedback are not possible because so few studies examined delayed feedback and almost never did so with children under age seven. Future research should systematically evaluate these feedback features at different ages.

The Role of Individual Learner Differences

The 44 papers were consistent with the literature in demonstrating that learner characteristics can be as important, if not more so, as features of the feedback itself (e.g., Narciss & Huth, 2004). A large portion of papers reported moderating effects, similar to classic aptitude-by-treatment interactions showing that one form of instruction can have positive effects for one group of learners and weaker or even reversed effects for another group (Cronbach & Snow, 1977). A variety of characteristics were considered (e.g., gender, working memory), but the most prevalent was some form of prior knowledge or experience with the topic. Prior knowledge is frequently considered in the larger feedback literature as learning involves integrating new information with information stored in long-term memory (Sweller et al., 1998).

The most consistent finding was for feedback to have stronger positive effects for children with low prior knowledge or experience relative to children with high prior knowledge or experience. This result resembles an expertise-reversal effect often reported in adults in which conditions with more external guidance are likely to benefit novices and conditions with less external guidance are likely to benefit experts (see Kalyuga, 2007). High-knowledge learners may waste cognitive resources by processing both internal and external information that is redundant. These findings are noteworthy because they suggest feedback directed at children may at times be *un*helpful and the ways in which researchers consider and measure prior knowledge matters (e.g., domain-general vs. domain-specific) for enhancing learning outcomes.

Again, the disconnected nature of the literature is relevant as studies focused on prior knowledge were somewhat overrepresented in the topic of mathematics; thus, research and theory in other topics need to consider interactions between feedback and prior knowledge to better understand the generalizability of such patterns. Also, additional learner characteristics that have been hypothesized to matter for learning– including interest and self-efficacy (Bangert-Drowns et al., 1991) – were not considered at all and it could be fruitful for theoretical models of feedback processing to more precisely incorporate these characteristics and for empirical research to investigate how they influence the effectiveness of corrective feedback.

The State of the Field, Limitations, and Future Directions

The 44 papers in the current review are rigorous demonstrations of how feedback influences children's learning, and they lead to some tentative recommendations for future research and practice (see Figures 5 and 6). Each paper is unique, valuable, and offers rich nuance in its conclusions. Overall, the researchers tended to spotlight the benefits of corrective feedback for children in preschool and elementary school, while simultaneously recognizing that the effects of feedback are variable and that other supports may be needed to optimize children's learning. Looking across the papers, however, reveals that the state of the field is fragmented given the siloed programs of research within each topic. Some forms of feedback have been studied using a paradigm with one age group or topic and using a different paradigm or not at all with a different age group or topic. These gaps and misalignments create barriers to forming robust conclusions about the effectiveness of feedback as it is hard to discern whether different effects are due to developmental changes, design differences, or replication failures.

There are at least four major gaps which can motivate updates to theory and future empirical research. First, regarding feedback content, the examination of explanation prompts was rare, and exceedingly rare in older children. Research is needed to evaluate the potential advantages and disadvantages of including this additional information in the feedback message for both younger and older children. Cognitive load theory may help shed light on how changing the amount or complexity of information in the feedback message interacts with developmental changes in domain-specific knowledge, attention, and working memory (Sweller et al., 1998).

Second, although quite a few studies included some form of feedback alert, these alerts were primarily investigated with 8-year-olds in the domain of literacy. Research is needed to evaluate their necessity across a range of ages and areas, and to consider whether "feedback alerts" should be included as a new "Stage 2" in the model of feedback processing before the target question is even posed (i.e., prior to the current Stage 2). For example, researchers could experimentally compare a feedback condition with, versus without, a prior alert and assess how it influences children's abilities to notice and make sense of the feedback message. This type of research could inform theories on feedback processing and whether knowing that feedback is forthcoming alters learners' cognitive or affective states during the target task.

Third, the outcome measures predominantly focused on in-the-moment performance or immediate posttest performance, but more efforts are needed to consistently assess maintenance over time (especially in mathematics and problem solving) and transfer to untrained tasks (especially in literacy). Expanding this research to consider affective outcomes – such as motivation to continue the task or threats to self-esteem (e.g., Hendriks et al., 2021; Mangels et al., 2012) – might also be fruitful. For example, one research group noted that children found feedback less enjoyable, especially feedback on incorrect responses (Muis et al., 2015). However, most researchers only speculated on how feedback influenced these affective components rather than measuring them. Feedback theories may need to be elaborated to better delineate how affective and cognitive outcomes interact, especially after negative feedback.

Fourth, the training protocols (e.g., number of sessions, setting) varied widely based on the program of research, but studies in problem solving and mathematics domains were predominantly conducted in controlled one-on-one settings with a single training session. These protocols should be expanded to include a wider range of study contexts (e.g., class-wide training sessions) to truly evaluate the strength of feedback effects in these topics.

More broadly, researchers focused on one domain should consider how feedback is studied in other domains. One concrete example is the performance feedback in the literacy topic that is provided during a class wide writing intervention (e.g., Hier & Eckert, 2014). In these studies, children practiced writing a narrative over multiple sessions, and received feedback indicating the number of words they had written and whether this amount increased or decreased relative to prior attempts. This same type of feedback could potentially be adapted to help children gain fluency with arithmetic practice (how many solved), with reading novel words (how many read), or with adhering to new rules on a problem-solving task (how many sorted). Studying corrective feedback in these cross-domain ways may help fine-tune theories that speculate on the mechanisms by which feedback alters students' performance.

Conclusion

Overall, we propose that the papers reviewed here support a developmental perspective that feedback unfolds within a dynamic system and that brief in-the-moment experiences with feedback *can* create knowledge change. The variable effects across the papers suggest that different factors within the system, including the type of feedback provided and the type of outcome assessed, can shape the level of learning that occurs. Critically, the synthesis of these papers has clear theoretical implications for how feedback manifests for young students, what effects it has, and why. The pattern of findings suggests that theories of feedback (a) should be elaborated to incorporate the positive effects of corrective feedback across a greater range of the lifespan, (b) should delineate more specific steps of feedback processing, including steps that may occur before the target task, and (c) should consider a greater range of learner characteristics and outcome measures to help explain when the benefits of feedback will occur and for whom. The more researchers attend to the learner's state and to characteristics that vary across development, the better theories of feedback processing can specify the mechanisms that lead to cognitive change in response to feedback in early childhood education.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Merrick was supported by a training grant from the Eunice Kennedy Shriver National Institute of Child Health and Human Development of the National Institutes of Health under Award Number T32HD007475. The content is solely the responsibility of the authors and does not represent the official views of the National Institutes of Health.

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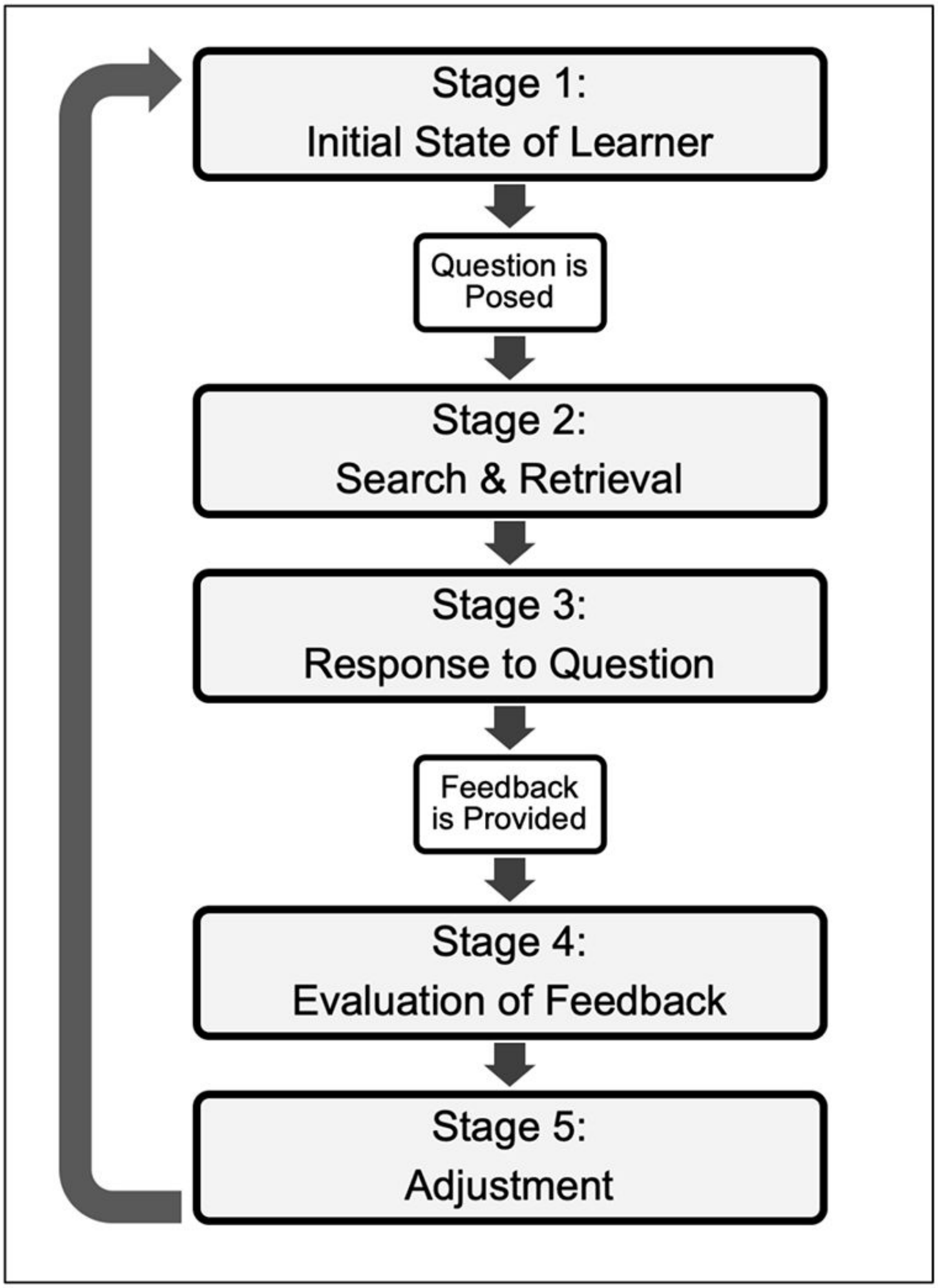

Figure 1.
Five-stage model of feedback processing by Bangert-Drowns et al. (1991)

Authors & Year	Topic	Sample	Setting	Manipulated Conditions	Training Length	Outcome Measures	Results
Truckenmiller, Eckert, Codding, Petscher (2014)	Writing Fluency	133 3rd graders (age 8)	Whole classroom	Performance FB; Performance FB in control topic (math); Practice Only	8 practice sessions over 8 weeks	Performance during training	Positive effect of FB relative to both control conditions
Hier & Eckert (2014)	Writing Fluency	103 3rd graders (age 8)	Whole classroom	Performance FB; Practice Only	6 practice sessions over 6 weeks	Performance during training; Maintenance 2, 4, and 6 weeks later	Positive effect of FB on training; No effect of FB on maintenance
Hier & Eckert (2016)	Writing Fluency	118 3rd graders (age 8)	Whole classroom	Performance FB; Performance FB + Variable Practice Examples; Practice Only	6 practice sessions over 6 weeks	Performance during training; One-week Posttest; Maintenance 4 months later	Positive effect of Performance FB on training; Only Variable Practice led to maintenance over time
Koenig, Eckert, & Hier (2016)	Writing Fluency	*115 3rd graders (age 8-9)	Whole classroom	Performance FB; Performance FB + Writing Goal; No Input Control	6 practice sessions over 6 weeks	Performance during training	Positive effects of both FB conditions relative to control
Hier, Eckert, & Viney (2019)	Writing Fluency	*115 3rd graders (age 8-9)	Whole classroom	Performance FB; Performance FB + Writing Goal; No Input Control	6 practice sessions over 6 weeks	One-week-later Posttest; Maintenance 4 weeks later	No effect of FB on posttest or maintenance
Nobel & Grünke (2020)	Writing Fluency	30 4th graders (age 8-9)	Computers at school	Performance Feedback + Strategy; Business as Usual	7 training sessions over 2 weeks	Next-day Posttest	Positive effect of FB relative to Business as Usual control
Spaai, Ellermann, & Reitsma (1991)	Reading Accuracy	60 1st graders (age 7)	One-on-one	Whole Word Answer FB; Segmented Word Answer FB; Practice Only	3 practice sessions over 3 days	Next-day Posttest	Positive effects of both FB conditions relative to No FB
	Reading Accuracy	66 1st graders (age 6)	One-on-one	Whole Word Answer FB; Segmented Word Answer FB; Practice Only	3 practice sessions over 3 days	Next-day Posttest	Positive effect of Whole-Word FB; Neutral effect of Segmented Word FB
van Gorp, Segers, & Verhoeven (2017)	Reading Accuracy	95 1st graders (age 6-7)	One-on-one at school	Whole Word Answer FB; Whole Word + Segmented Answer FB; Practice Only	10 practice sessions	Performance during training; Next-day Posttest; Maintenance 14 days later	Good readers benefit from No-FB and poor readers benefit from Segmented FB for training. Minimal effects on posttest and maintenance.
Martin-Chang (2017)	Reading Accuracy	28 2nd graders (age 6-8)	One-on-one at school	Whole Word Answer FB; Practice Only	5 practice sessions over 2 weeks	Performance during training; Week-later Posttest	Positive effects of FB relative to No FB
Martin-Chang, Ouellette, & Bond (2017)	Reading Accuracy	23 2nd graders (age 7)	One-on-one at school	Whole Word Answer FB; Practice Only	4 practice sessions over 1 week	Next-day Transfer Spelling; One-week-later Posttest	Positive effects of FB for training and posttest. No effects of FB on spelling.
Kegel, Bus & van Ijzendoorn (2011)	Letter Knowledge; Phonology	*182 primary schoolers (age 4-5)	Computers at school	Prompts + Correct Answer FB on literacy practice; Practice Only; Irrelevant Task Control	15 training sessions over 4 months	Immediate Posttest	Positive effect of FB for those with dopamine gene variant; Neutral effect for others
Kegel & Bus (2012)	Letter Knowledge; Phonology	*312 kindergarten (age 4)	Computers at school	Prompts + Correct Answer FB on literacy practice; Practice Only; Irrelevant Task Control	15 training sessions over 4 months	Immediate Posttest	Positive effect of FB relative to both control conditions; stronger for low inhibition
Kao, Tsai, Liu & Yang (2016)	Reading Comprehension	40 4th graders	Tablets at school	Prompts + Correct Answer FB on storybooks; Practice Only	1 training session	Same-day Posttest; Motivation	Positive effect of FB relative to No FB
Patchan & Puranik (2016)	Writing Letters	54 preschoolers (age 4)	Tablets in school	Tablet Try-Until Correct FB; Paper & Pencil Control	24 training sessions over 8 weeks	One-week-later Posttest	No effect of FB on posttest
Muis, Ranellucci, Trevors, & Duffy (2015)	Letter ID, Phonemes	31 kindergarten (age 6)	Tablets at school	Verification + Try-Until Correct FB; Practice Only	1 practice session	Performance during training	Positive effect of FB on accuracy; Negative effect of FB on enjoyment
	Letter ID, Phonemes	33 kindergarten (age 5)	Tablets at school	Verification + Try-Until Correct FB; Practice Only	1 practice session at beginning and 1 at end of school year	Performance during training	Start of year negative effect of FB on engagement; End of year positive effect of FB on accuracy relative to control
Bonneton-Botté, Fleury Girard et al. (2020)	Handwriting	233 kindergarten (age 5-6)	Tablets at school	Error FB + Correct Answer; Paper and Pencil Practice Only	12 weeks of regular school time	Two-week-later Posttest	Positive effect of FB only for moderate knowledge children
Rieben, Ntamakiliro, Gonthier & Fayol (2005)	Writing Letters, Reading Words, Spelling Words	145 kindergarten (age 4-5)	Small groups at school	Correct Answer FB on Spelling; Practice Only; Copy Words Control; Irrelevant Task	18 training sessions over 6 months	Immediate Posttest	Positive effects of FB relative to Irrelevant Task control
Damhuis, Segers & Verhoeven (2015)	Vocabulary	125 kindergarten (age 4-5)	Small groups at school	Correct Answer FB; Testing without FB; Repeated Storybook Reading without FB; Storybook Reading Alone	3 reading or testing sessions over 3 weeks	One-week-after Posttest	Positive effect of FB relative to Testing; Neutral effect of FB relative to Repeated Storybook Reading

Figure 2. Study characteristics within literacy (n = 18 papers, n = 20 experiments)

Note. Abbreviations: FB = Feedback; * = experiments that have overlapping samples

Authors & Year	Topic	Sample	Setting	Manipulated Conditions	Training Length	Outcome Measures	Results
Dihoff, Brosvic, Epstein & Cook (2005)	Arithmetic Facts	10 2[nd] graders with MLD (age 10)	Resource room at school	Immediate FB from person; Immediate FB using scratch-off form; Delayed FB using scantron form; Practice Only	15 practice sessions over 3 days	Performance during training; Maintenance 5 days later	Positive effects of all FB conditions relative to No FB; Positive effect of Immediate FB relative to Delayed FB
	Arithmetic Facts	16 3[rd] graders with MLD (age 11)	Resource room at school	Immediate FB from Person; Immediate FB using scratch-off form; Combined FB from Person and scratch-off form; Practice Only	15 practice sessions over 3 days	Performance during training; Maintenance 5 days later	Positive effects of all FB conditions relative to No FB; Combined condition best
	Arithmetic Facts	24 4[th] graders with MLD (age 12)	Resource room at school	Immediate FB using scratch-off form; Practice Only	7 practice sessions over 7 days	Performance during training; Maintenance 14 days later	Positive effects of FB relative to No FB
Brosvic, Dihoff, Epstein & Cook (2006)	Arithmetic Facts	40 3[rd] graders with MLD (age 10)	Resource room at school	Immediate FB from Person; Immediate FB using scratch-off form; Delayed FB using scantron form; Practice Only	20 practice sessions over 10 days	Performance during training; Maintenance 5 days later	Positive effects of all Immediate FB conditions relative to No FB
	Arithmetic Facts	40 3[rd] graders with MLD (age 10)	Resource room at school	Immediate FB from Person; Immediate FB using scratch-off form; Immediate FB from Person with try-again; Practice Only	20 practice sessions over 10 days	Performance during training; Maintenance 5 days later	Positive effects of all Immediate FB conditions relative to No FB
Labuhn, Zimmerman & Hasselhorn (2010)	Order of Operations	90 5th graders (age 10)	One-on-one at school	Performance FB; Social Comparison FB; Practice Only	1 practice session	Same-day Posttest; Self-Evaluative Judgments	No effects of FB on posttest; Positive effects of FB on self-evaluation accuracy
Duhon, House, Hastings, et al. (2015)	Arithmetic Facts	48 2nd graders (age 7-8)	Computers at school	Verification FB; Practice Only; No Input Control	20 practice sessions over 20 days	Three-day-later Posttest	Positive effect of FB relative to both control conditions
Messer, Mohamedali & Fletcher (1996)	Time	51 primary schoolers (age 7-8)	Computers at school	Immediate Correct Answer FB; Delayed Correct Answer FB; Practice Only	1 practice session	Same-day Posttest; Maintenance 7 days later	Similar gains in Immediate FB and No FB conditions; No gains in Delayed FB
	Time	41 primary schoolers (age 8-9)	Computers at School	Immediate Correct Answer FB; Practice Only	1 practice session	Same-day Posttest	Similar gains in Immediate FB and No FB conditions
	Time	61 primary schoolers (age 6-10)	Computers at School	Verification + Try Again FB; Correct Answer + Try Again FB; Correct Answer + New Example FB; Practice Only	1 practice session	Same-day Posttest	Similar gains in all FB and No-FB conditions
Fazio, Kennedy & Siegler (2016)	Fraction Number Line	51 5th graders (age 10)	Computers at school	Correct Answer FB embedded in game; Practice Only	1 practice session	Same-day Posttest with Magnitude tasks and Fraction Recall tasks	Positive effects of FB on magnitude tasks; No effects of FB on fraction recall
Fyfe (2016)	Algebra	103 5th & 6[th] graders (age 10-11)	Computers at school	Correct Answer FB; Practice Only	1 homework	Same-day Posttest	Positive effect of FB for low knowledge; Neutral effect of FB for high knowledge
Faber, Luyten & Visscher (2017)	Arithmetic, Geometry, Time, Money	1808 3[rd] graders (ages 8-9)	Tablets at school	Verification FB embedded in digital tool; Business as Usual	5 months	Immediate Standardized Assessment; Motivation	Positive effect of FB for achievement and motivation; Stronger for high knowledge
Alibali (1999)	Math Equality	143 3[rd] & 4[th] graders (age 8-9)	One-on-one at school	Verification FB; FB + concept instruction; FB + procedure instruction; FB + analogy instruction; Practice Only	1 practice session	Same-day Posttest	Neutral effect of Verification FB, Positive effects of FB with instruction relative to No FB
Fyfe, Rittle-Johnson, & DeCaro (2012)	Math Equality	87 2[nd] & 3rd graders (age 7-8)	One-on-one at school	Correct Answer FB; Strategy FB; Practice Only	1 practice session	Same-day Posttest with Procedural task and Conceptual task; Maintenance 14 days later	No effects of FB on concepts; Positive effects of FB for low knowledge; Negative effects of FB for high knowledge
	Math Equality	95 2[nd] & 3rd graders (age 7-8)	One-on-one at school	Verification FB; Strategy FB; Practice Only	1 practice session	Same-day Posttest with Procedural task and Conceptual task; Maintenance 14 days later	No effects of FB on concepts; Positive effects of FB for low knowledge; Negative effects of FB for high knowledge
Fyfe & Rittle-Johnson (2016a)	Math Equality	108 2[nd] & 3rd graders (age 7-9)	One-on-one at school	Verification FB; Practice Only	1 practice session	Same-day Posttest with Procedural task and Conceptual task	No effects of FB on concepts; Positive effects of FB for low knowledge; Negative effects of FB for high knowledge
	Math Equality	101 2[nd] & 3rd graders (age 7-9)	One-on-one at school	Immediate Correct Answer FB; Delayed Correct Answer FB; Practice Only	1 practice session	Same-day Posttest with Procedural task and Conceptual task	Negative effects of both FB types for high knowledge on procedures and concepts
Fyfe & Rittle-Johnson (2016b)	Math Equality	75 2nd graders (age 7-9)	One-on-one computers at school	Immediate Correct Answer FB; Delayed Correct Answer FB; Practice Only	1 practice session	Performance during training; Next-day Posttest with Procedural task	Positive effects of FB; stronger for low knowledge; stronger for Immediate FB
Fyfe & Rittle-Johnson (2017)	Math Equality	243 2[nd] & 3rd graders (age 6-10)	Small groups at school	Immediate Correct Answer FB; Delayed Correct Answer FB; Practice Only	1 practice session	Performance during training; Same-day Posttest; Maintenance 7 days later	Positive effect of Immediate FB on performance; Neutral or negative effects of FB on posttest and maintenance
Brown & Alibali (2018)	Math Equality	106 2[nd] & 3rd graders (age 7-10)	One-on-one in lab	Verification FB; Practice Only	1 practice session	Same-day Posttest with Procedural Task and Conceptual Task	FB inhibited strategy change for low knowledge; FB increased strategy change for low confidence

Figure 3. Study characteristics within mathematics (n = 14 papers, n = 21 experiments)

Note. Abbreviations: FB = Feedback; MLD = Mathematics Learning Disability

Authors & Year	Topic	Sample	Setting	Manipulated Conditions	Training Length	Outcome Measures	Results
Bohlmann & Fenson (2005)	Card Sort	40 preschoolers (age 3-5)	One-on-one in lab	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training	Positive effect of FB relative to No FB
	Card Sort	24 preschoolers (age 3)	One-on-one in lab	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Same-day Posttest	Positive effect of FB on training relative to No FB; No effect on posttest
Espinet, Anderson, & Zelazo (2013)	Card Sort	29 preschoolers (age 2-4)	One-on-one in lab	Correct Answer FB on incorrect trials + Reflection; Practice Only	1 practice session	Next-day Posttest; Next-day Far Transfer to False Belief Task	Positive effect of FB on posttest; No effects on far transfer
	Card Sort	28 preschoolers (age 2-4)	One-on-one in lab	Correct Answer FB on incorrect trials + Reflection; Practice Only	1 practice session	Next-day Posttest; Next-day Far Transfer to False Belief Task	Positive effect of FB on posttest; No effects on far transfer
	Card Sort	56 preschoolers (age 2-4)	One-on-one in lab	Correct Answer FB; Correct Answer FB + Reflection; Practice Only	1 practice session	Performance during training; Next-day Posttest	Positive effect of both FB conditions on training; Positive effect of Reflection group on posttest
van Bers, Visser, & Raijmakers (2014)	Card Sort	56 preschoolers (age 3-4)	One-on-one in school	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Same-day Posttest; Maintenance 7 days later	Positive effect of FB relative to No FB
	Card Sort	51 preschoolers (age 3)	One-on-one in school	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Same-day Posttest; Maintenance 7 days later	Positive effect of FB relative to No FB
	Card Sort	52 preschoolers (age 3)	One-on-one in school	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Same-day Generalization	Positive effect of FB relative to No FB
Tarullo, Nayak, St. John, & Doan (2018)	Card Sort	105 preschoolers (age 3-4)	One-on-one in lab	Verification Feedback with Sticker Reward; No Feedback	1 practice session	Performance during training	Positive effect of FB, but longer response times
van Bers, van Schijndel, Visser, & Raijmakers (2020)	Card Sort	51 preschoolers (age 3)	One-on-one in School	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Maintenance 7 days later	Positive effect of FB relative to No FB
	Card Sort	62 preschoolers (age 3)	One-on-one in school	Verbal and Physical Correct Answer FB; Practice Only	1 practice session	Performance during training; Maintenance 7 days later; Far Transfer to cognitive task	Positive effect of FB on training and maintenance; No effect of FB on transfer
Honomichl & Chen (2006)	Analogical Reasoning	59 pre-K and K (age 3-5)	One-on-one in lab or school	Correct Answer FB + Explanation; Practice Only	1 practice session	Performance during training	Positive effect of FB relative to No FB; Stronger effect for older children
Chiu & Alexander (2014)	Analogical Reasoning	80 preschoolers (age 5)	One-on-one at school	Verification + Try Again until Correct FB; Practice Only	1 practice session	Performance during training	Positive effect of FB relative to No FB
Chen, Honomichl, Kennedy & Tan (2016)	Analogical Reasoning	33 primary schoolers (age 5-6)	One-on-one in lab	Correct Answer FB + Explanation; Practice Only	1 practice session	Performance during training	Positive effect of FB relative to No FB
Stevenson (2017)	Analogical Reasoning	999 K - 4th grade (age 4-11)	Computers at school	Gradual Prompts + Correct Answer FB; Verification + Try Again until Correct FB; Practice Only	2 practice sessions	Next-day Posttest	Both FB types better than control; Prompts better than Verification; Better for high WM, low prior knowledge
Touw, Vogelaar, Thissen, Rovers & Resing (2020)	Relational Patterns	164 2nd graders (age 6-9)	Tablets at school	Gradual Prompts + Correct Answer FB; Irrelevant Task Control	2 practice sessions over 2 weeks	One-week-later Posttest	Positive effect of FB on gains from pretest to posttest
Tudge & Winterhoff (1993)	Balance Scale	81 Kindergarten (age 5-6)	One-on-one or partners in school	Physical Verification FB; Practice Only	3 practice sessions	Three-day-later Posttest; ~One-month-later Posttest	Positive effects of FB over time; Stronger for children with more school experience
Tudge, Winterhoff, & Hogan (1996)	Balance Scale Task	180 1st & 2nd graders (age 6-9)	One-on-one or partners in school	Physical Verification FB; Practice Only	1 practice session	Six-day-later Posttest; Four-Week-later Posttest	Positive and stable effects of FB relative to No FB

Figure 4. Study characteristics within problem solving (n = 12 papers, n = 18 experiments)

Note. Abbreviations: FB = Feedback

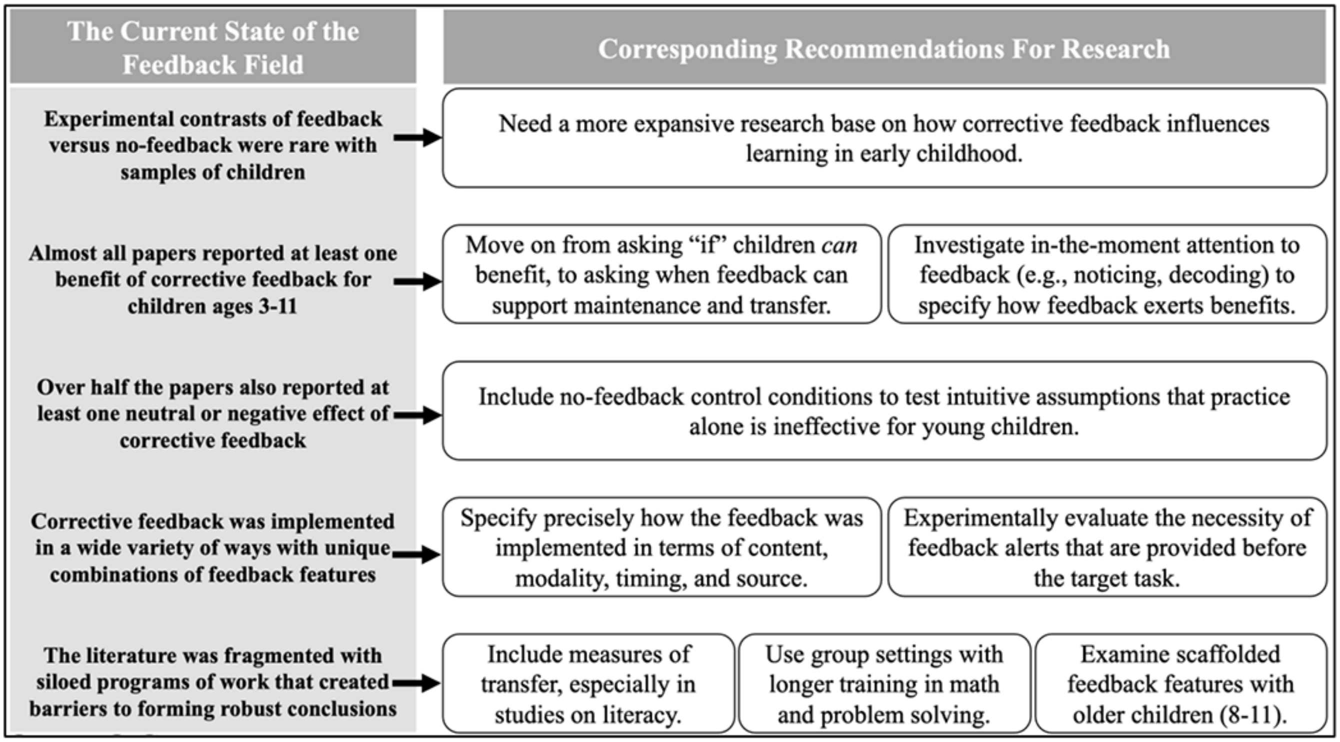

Figure 5.
The state of the field and corresponding recommendations for research

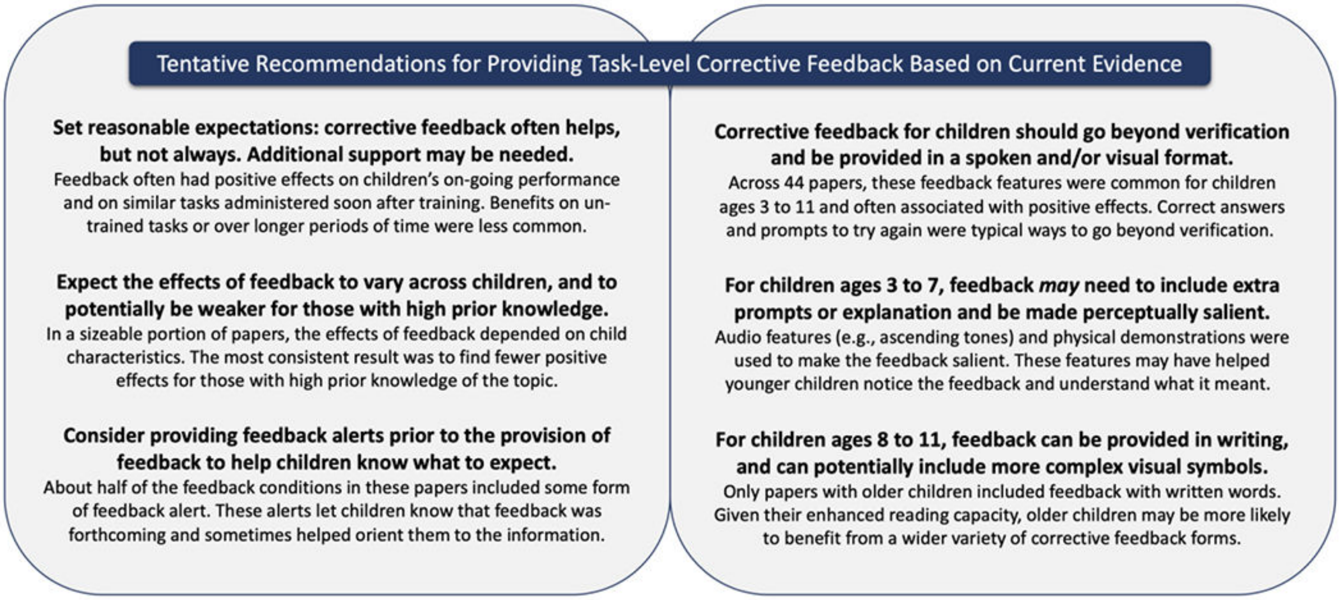

Figure 6.
Tentative recommendations for practice

Table 1

Frequency of different feedback features within each of the unique 60 feedback conditions as a function of age group

	Feedback Alert	Feedback Content				Feedback Modality					Feedback Timing		Feedback Source		
Sample Information	***Present***	***Verify***	***Try again***	***Correct answer***	***Prompts/ Explain***	***Spoken words***	***Written words***	***Audio symbols***	***Visual symbols***	***Physical***	***After each item***	***After all items***	***Person***	***Computer***	***Paper***
Age 3 to 5	5/15 (.33)	13/15 (.87)	5/15 (.33)	12/15 (.80)	5/15 (.33)	10/15 (.67)	0/15 (.00)	3/15 (.20)	5/15 (.33)	3/15 (.20)	14/15 (.93)	1/15 (.07)	9/15 (.60)	8/15 (.53)	0/15 (.00)
Age 6 to 7	3/10 (.30)	7/10 (.70)	3/10 (.30)	7/10 (.70)	2/10 (.20)	7/10 (.70)	0/10 (.00)	2/10 (.20)	4/10 (.40)	2/10 (.20)	10/10 (1.00)	0/10 (.00)	4/10 (.40)	6/10 (.60)	0/10 (.00)
Age 8 to 9	18/24 (.75)	22/24 (.92)	4/24 (.17)	11/24 (.46)	3/24 (.12)	15/24 (.63)	12/24 (.50)	0/24 (.00)	10/24 (.42)	0/24 (.00)	20/24 (.83)	4/24 (.17)	15/24 (.63)	14/24 (.58)	7/24 (.29)
Age 10 to 11	2/11 (.18)	9/11 (.82)	6/11 (.55)	10/11 (.91)	0/11 (.00)	4/11 (.36)	2/11 (.18)	0/11 (.00)	9/11 (.82)	0/11 (.00)	8/11 (.73)	3/11 (.27)	5/11 (.45)	2/11 (.18)	6/11 (.55)
All ages combined	28/60 (.47)	51/60 (.85)	18/60 (.30)	40/60 (.67)	10/60 (.17)	36/60 (.60)	14/60 (.23)	5/60 (.08)	28/60 (.47)	5/60 (.08)	52/60 (.87)	8/60 (.13)	33/60 (.55)	30/60 (.50)	13/60 (.22)

Note. The raw numbers represent the number of feedback conditions in that age range that contain the relevant feature. The numbers in parentheses represent the proportion of feedback conditions in that age range that contain the relevant feature.