Towards a Set of Design Principles for Computer-Mediated Feedback Fostering Teachers' Pedagogical Skills: A Synthesis of the Literature

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Abstract Developing pedagogical skills of teachers is an essential objective in teacher education. Although feedback from workplace supervisors is considered crucial for encouraging these skills in the first stages of teachers' careers, delivering effective and just-in-time feedback is under pressure due to a teacher shortage in secondary education. Recent technological developments allow alternative sources to deliver feedback provided by innovative technologies. However, a comprehensive picture of effective characteristics of computer-mediated feedback (CMF) is lacking. Therefore, this review identifies studies with the aim of deducing a set of design principles for CMF fostering pedagogical skills. Subsequently, all studies were categorized with respect to learning environment characteristics, learning processes and learning outcomes. The synthesis is a set of principles including personalized, immediate and delayed feedback. Finally, a future research agenda focuses on how these principles could optimize innovative technologies to deliver feedback for teachers in daily practice.

Keywords: pedagogical skills, computer-mediated feedback, design principles, teachers, systematic review.

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1 Introduction

A global shortage of 69 million teachers is putting pressure on the education system (Adubra et al., 2019). Furthermore, the issue is exacerbated as an analysis was published by the Dutch Ministry of Education which concluded that there was an attrition rate of more than 30% of teachers younger than 30 years of age in secondary education within the first five years of their career (Ministry of Education, Culture and Science, 2014). Many countries have similar attrition rates such as: 40% in the US based on a survey, (Ingersoll, 2003), and 30-40% in Australia (Ewing & Manuel, 2005). Of all teachers, 33% dropped out of the profession within five years in the UK (Education Policy Institute, 2021).

To reduce the amount of teachers dropping out, national policies have been aimed at induction. Induction can be defined as "a planned program intended to provide some systematic and sustained assistance specifically to beginning teachers for at least one school year" (Helms-Lorenz et al., 2016). However, this support is under immense pressure as schools struggle to provide induction due to the current teacher shortage.

Novice teachers mainly struggle in the first period of their career with pedagogical skills like classroom management. Pedagogical skills can be defined as "...the ability and willingness among teachers to consistently apply those attitudes, knowledge and skills that promote their students' learning in the best possible way, in accordance with set goals and within the limits provided. This calls for continuous development of teachers' own competence and the design of the teaching" (From, 2017, p.47). Feedback given by coaching and observing (in relation to these pedagogical skills) is the most powerful induction ingredient measured in a longitudinal study on the effects of induction programs (Helms-Lorenz, van der Grift & Maulana, 2016). Feedback is one of the greatest influences on learning and achievement (Hattie & Timperley, 2007). However, as few teachers and coaches are available to provide this induction, there is a need to search for other solutions. There are alternative sources which can provide effective feedback through computers (Schneider et al, 2016; Lavolette et al, 2015). One such example is the use of virtual reality to foster presentation skills (van Ginkel et al, 2019). Therefore this support could be given in the form of computer-mediated feedback (CMF).

There are several reported affordances of CMF in a variety of learning situations such as enhancing: achievement, engagement, gamification, facilitating collaborative learning and real time error correction (Bahari, 2020). Bahari (2020) goes on to state that one of the challenges of providing effective CMF, is that many elements of feedback have not been widely explored. One element of CMF which is studied in language acquisition pertains to whether to use immediate or delayed feedback (Lavolette et al., 2015).

While previous studies have focused mainly on the effect of CMF on students' performances regarding various tasks and skills, proper research on the implementation of CMF to assist teachers is lacking hitherto. In addition, no comprehensive list of design principles for CMF was found in the relevant literature. Thus there is a fragmented picture of design principles of CMF as many of these principles are studied individually rather than being studied as an integrative set. That is why the aim of this systematic review is to distil a comprehensive set of effective CMF components for the development of pedagogical teacher competencies. Such a set of design principles would be of inestimable value to people creating CMF systems of any kind.

This systematic review has been conducted to ascertain what elements of effective CMF are required to develop pedagogical teacher competencies and to synthesize these elements into a comprehensive framework for design principles of CMF. The main question which was to be answered was: How to design CMF in order to foster pedagogical competencies of a teacher?

To conclude, this specific systematic research will provide insight into how to design how to design CMF in order to foster pedagogical competencies of a teacher. The incorporation of these design principles in a computer system utilizing CMF would have several affordances including: increasing the quality of teaching in the classroom, reducing the workload for teachers, creating an alternative for coaching and support of expert teachers, and decrease the dropout rate for novice teachers.

2 Method

The current systematic review attempts to identify the characteristics of effective CMF in order to foster teachers' pedagogical skills. In terms of the characteristics of the learning environment, two classes are identified namely feedback characteristics and system characteristics (van Ginkel et al., 2015). To support the effectiveness of feedback characteristics, system characteristics are identified. System characteristics relate to elements of the learning environment which are not related to the feedback itself, but instead facilitate the usage of such feedback systems. Feedback characteristics include all characteristics both objective and subjective related to the feedback.

The methodological approach regarding the analysis of the articles contained in our yield has been conducted based on the Biggs model (2003) which is a widely accepted framework within the educational sciences. Furthermore, it is a framework within which the categories are broad enough to be able to incorporate the results of this review. Biggs (2003) identifies three separate categories 1) learning environment, 2) learning processes and 3) learning outcomes (see figure 2). Category one contains feedback characteristics or design principles that constitute the independent variable. Category two constitutes the method or argument through which these elements in the learning environment influence category three (performance, which is the dependent variable). After selecting the characteristics of the learning environment and their effects on performance, these aspects were synthesized into design principles following the formula created by van den Akker (1999, p.5). The formula is as follows: "If you want to design intervention X (for the purpose/function Y in context Z), then you are best advised to give that intervention the characteristics A, B, and C (substantive emphasis), and to do that via procedures K, L, and M (procedural emphasis), because of arguments P, Q, and R". Thus design principles in the context of this study are principles which should be adhered to when creating CMF in order to foster teacher's pedagogical skills.

This following section will start with the inclusion criteria that are formulated. Then the search strategy is laid out accordingly, describing the independent and dependent variables. The relevant publications are identified and finally these publications are explored, analyzed and the relevant CMF elements synthesized into a comprehensive framework.

2.1 Formulation of criteria for inclusion

Various inclusion criteria have been formulated. To start with the first requirement, (1) papers were included which were empirical in nature in which automated feedback is related to the competencies of teachers. This is due to the aim of investigating the effectiveness of CMF elements which therefore require empirical studies such as randomized controlled trials. Second, (2) the articles must be in the context of secondary or higher education as the CMF will be focused on teacher pedagogical competencies. In addition, (3) only peer-reviewed articles were included in the results to obtain scientific fidelity. Finally, (4) the time frame is limited from 2010 to 2021 because the rise of innovative technologies such as virtual reality that support feedback started around 2010 (Ministry of Education, Culture and Science, 2019) and we are interested in design principles supporting feedback.

2.2 Development of a search strategy

The keywords for the independent variable were retrieved by starting with keyword searches such as "feedback" and "computer*" after which relevant search results were screened for related keywords and synonyms. The same process is repeated for the dependent variable. A few examples of independent variables that have been included are: "augmented", "instruction", "feedback", "automated". For the dependent variable examples of included keywords were: "performance", "skills", "competenc*". After an exhaustive list of dependent and independent variables had been selected, every combination of the two variables was searched for, with the additional condition being the context of secondary and higher education. This was done by combining all variables in Web of Science with the TOPIC "school" and "educ*". Web of Science (WoS) is the leading scientific citation search platform in the world (Li et al., 2017). At first, a search was conducted with all variables set to TOPIC in Web of Science. However, this led to finding many irrelevant articles. To limit the number of results and to increase the accuracy of the search, the dependent variables were required to be in the title of the articles. In addition, three articles were added through the process of snowballing. This was done to obtain scientific fidelity as these relevant articles in the reference lists of our original yield did not show up based on our search strategy.

2.3 Identification of relevant publications

This systematic search strategy yielded 235 publications. After reviewing the abstract, publications were removed that: showed no relationship between the dependent and independent variable; did not focus on teacher competencies of a teacher or a student who needs to develop a teacher competency; are not published in English; do not include the context of secondary or higher education; or were not empirical in nature. Of the 235 publications which were identified, 199 did not include computer-mediated feedback or were not focused on teacher competencies. A further 19 publications were not conducted in the context of secondary or higher education. The article identification process was performed independently by two researchers to ensure inter-rater reliability. The overlap of choices to include or exclude articles from the yield of 235 publications made by the researchers is (Cohen's Kappa = 1). The Cohen's Kappa has been calculated based on a sample of 15 articles. Therefore, the inter-rater reliability was excellent.

3 Results

The result of this study is based on 17 articles of which three reviews and two meta-analyses which met the exclusion criteria (see figure 1). Out of these articles eight were randomized controlled trials and three were quasi-experimental studies. Further, one was an exploratory study that did have a pre and post-test but no control group. Most studies focused on language acquisition or non-verbal communication with students, for example vocabulary instruction, non-verbal communication, presentation competence, pronunciation, English writing, reflexive journal writing and grammar mechanics. Six studies were done in a non-lab setting classroom or otherwise realistic setting. All others were conducted in a lab or augmented reality/virtual reality setting. The studies were also analysed based on whether they were founded on an underlying theory such as cognitivism or constructivism. A couple of studies did use a fundamental underlying theory of learning, these are: Engeness & Mørch (2016) draw on Vygotskian cultural historical theory, Peeples and colleagues (2018) utilize a cognitive apprenticeship model, while Mirzaei and colleagues (2015) put Lewis's lexical view to the test. All characteristics of the learning environment have been taken into account when formulating the design principles which led to our final model of the seven design principles (see figure 2).

This section describes the seven design principles of CMF that were distilled (see figure 2). Each design principle has its origin in one or more of the publications which we have identified providing the argumentation for its practicability. In the following paragraphs the design principles are layed out in three steps. Firstly, the design principle is formulated including the independent and dependent variable. Secondly, it is stated how many of the articles supported that design principle. Thirdly, an example, taken from one of the 17 articles, of an argument which supports the design principle is given. For each design principle it is indicated what this means in a practical situation.

Coax memory and communicative performance by providing immediate feedback, because the learner can then make a cognitive comparison between the learner solution and the feedback which may have memory benefits. Out of the seventeen articles, five made use of immediate feedback. As suggested by Arroyo and Yilmaz (2018), there is a cognitive window of around 40 seconds that is open in which a comparison can be made by the learner between the current behaviour and the feedback which the learner has received.

Hone student performance by providing elaborative delayed feedback, which in turn induces an effect known as the spacing effect thereby providing an opportunity to re-study the learning material. Five articles made use of delayed feedback (although not necessarily elaborative) and a further four used both immediate feedback and delayed feedback or the timing was not clearly stated. There should be enough time between each feedback message in order to create a new opportunity to study the learning material (Candel et al., 2021).

Alleviate cognitive strain by delivering feedback in manageable units, thus decreasing this strain as a consequence of not receiving too much feedback at once. Consequently, this makes it easier to pay attention to the elements communicated to the learner. Four articles make use of manageable units one of which states explicitly that they make use of this technique. Indeed, Schneider and colleagues (2016, p.321) recognized this element and made sure to utilize manageable units in their randomized controlled trial. They state that "To limit the cognitive load at most one feedback-instruction is given at a time."

Temper cognitive load by delivering feedback using multimodal communication, thereby making it easier to pay attention to the elements communicated to the learner. Multimodal communication is the usage of multiple modes of communication such as: oral, written, haptic and video. This technique of multimodal communication has been made use of in one RCT. This reduced cognitive load makes it easier for the learner to pay attention to the elements communicated to him. Schneider and colleagues (2016) and Peeples and colleagues (2018) provided evidence in their RCT's for the efficacy of multimodal communication.

Buttress the perception of high frequency and high quality feedback by providing personalized feedback, because personalized feedback is seen as being more specific to the students' input. Two randomized controlled trials, two meta-analyses and one review study supported the use of personalized feedback. Furthermore learners feel as if there is more involvement in their progress, thereby increasing their satisfaction with learning. Deeva and colleagues (2021) show that students who receive online personalised feedback consistently have a higher performance and satisfaction with the course compared to students who receive generic feedback.

Optimize cognitive performance by allowing the learner to have a high perceived degree of learner control, because having this perceived control increases the learner's motivation. This design principle is supported by one review study. One of the situations in which a high perceived degree of learner control is beneficial in aiding cognitive performance is in a paired associate learning task, whereby memory is improved (Deeva et al., 2021). In this paired associate learning task, participants were tasked with remembering words in pairs, whereby one group choose the words which were ought to be remembered and the other group did not have a choice.

Trigger an increase in positive emotion by ensuring a low degree of anthropomorphic (human tendency to attribute human traits to non-human entities) human machine interaction because it leads to a sense of comfort. This design principle is supported by the review of Pérez and colleagues (2020). In conclusion, it is important to make clear to the learners that they are not interacting with a human but a computer bot (Pérez et al., 2020).

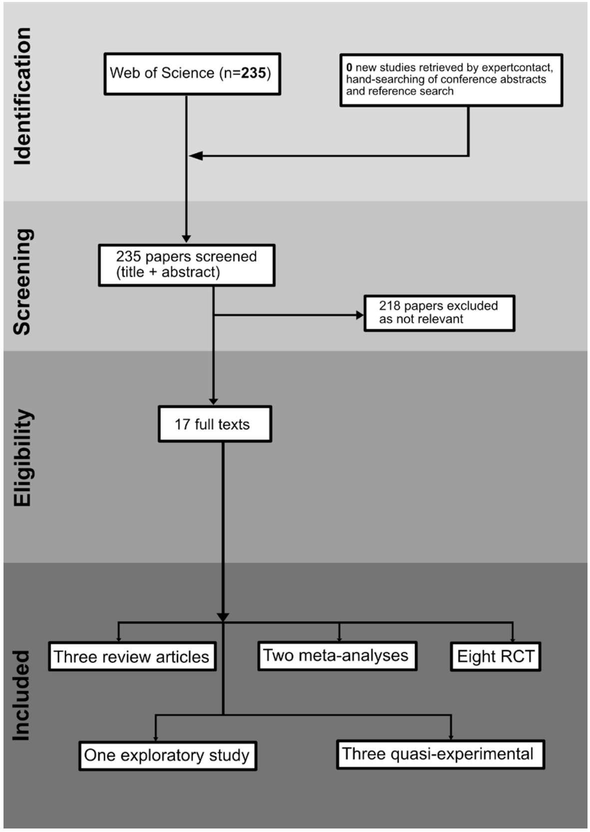

Figure 1: Flowchart of Identification, Screening, Eligibility and Included (yield)

Table 1: Literature yield and study characteristics per design principle

Design principle	Study's	Research design
1	Peeples et al. (2018)	RCT
	Pourhosein Gilakjani (2019)	RCT
	Schneider et al. (2016)	Quasi-experimental
	Lavolette et al. (2015)	Quasi-experimental
	Varank et al. (2014)	quantitative and qualitative
2	Candel et al. (2021)	RCT
	Van Ginkel et al. (2019)	RCT
	Wali & Huijser (2018)	Pretest-Posttest
	Cheng (2017)	RCT
	Engeness & Mørch (2016)	RCT
3	Peeples et al. (2018)	RCT
	Van Ginkel et al. (2020)	RCT
	Pourhosein Gilakjani & Rahimy (2019)	RCT
	Schneider et al. (2016)	Quasi-experimental
4	Schneider et al. (2016)	Quasi-experimental
	Peeples et al. (2018)	RCT
5	Deeva et al. (2021)	Review
	Little et al. (2018)	Meta-analyses
	Little et al. (2018b)	Meta-analyses
	Van Ginkel et al. 2019	RCT
	Schneider et al. (2016)	Quasi-experimental
6	Deeva et al. (2021)	Review
7	Pérez et al. (2020)	Review

Note. 1 (Immediate feedback), 2 (Elaborative delayed feedback), 3 (Manageable units), 4 (Multimodal communication), 5 (Personalized feedback), 6 (High perceived degree of learner control), 7 (A low degree of anthropomorphic human machine interaction)

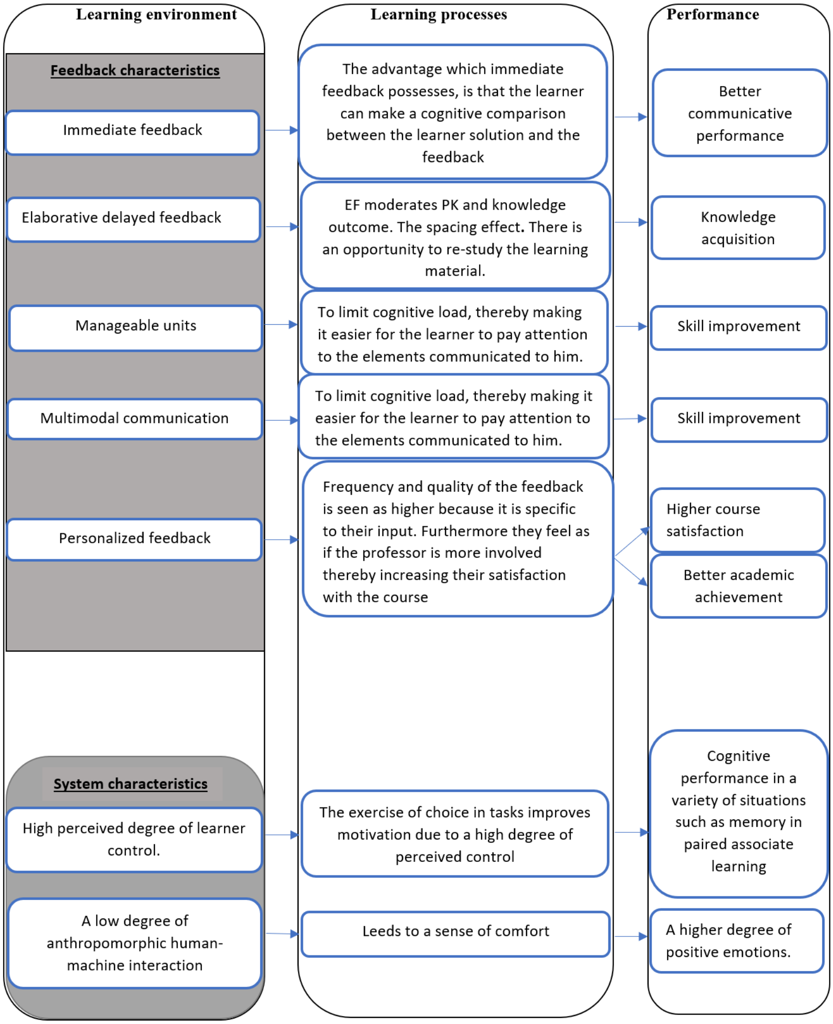

Figure 2: Framework for CMF to foster pedagogical teacher competence

4 Discussion

4.1 Concluding remarks

This study focuses on an alternative method for providing feedback to teachers about their pedagogical skills compared to face-to-face feedback from expert teachers. Reviewing the literature has led to seven design principles for providing effective CMF. These seven design principles are immediate feedback, elaborative delayed feedback, manageable units, multimodal communication, personalized feedback, high perceived degree of learner control, and a low degree of anthropomorphic human-machine interaction. However, relatively few empirical studies have been conducted looking at the efficacy of CMF. Furthermore, not a single comprehensive overview of design principles for CMF was encountered in this review suggesting that it is a relatively new terrain. All articles which were part of the yield did not utilize all design principles simultaneously. However, it is important to consider all seven design principles when developing a system which delivers CMF in order to extract the most utility from the system. Even though it is important to consider all design principles, based on the application of the system and its specific requirements, CMF system developers can make do without necessarily utilizing all seven design principles.

Several forms of CMF systems could be considered as these design principles will have to be integrated into a computer system. One system type that has increasingly been made use of and has seen much innovation in the past decade within the field of artificial intelligence (AI), is a chatbot. Chatbots are becoming more prevalent in various areas to take over routine information flows such as frequently asked questions. Another type of system which incorporates CMF is an interactive app for developing presentation skills, such as the Honest Mirror AI-driven app (Sakkali et al., 2021). Furthermore, theoretically all seven design principles could be used in concert in such a feedback system. Besides, the use of chatbots or interactive apps are advantageous to create a dynamic interaction between the learner and the system. The design principles which have been gathered in this review, have been found in the context of secondary and higher education and are therefore applicable in the education of teachers. It is not clear to what degree these principles could be used in other levels within education. This provides opportunity for others to test whether these principles could be applied more broadly.

4.2 Limitations

Firstly, a limitation of this study was that the population in many studies were students and not teachers. Therefore, it is not certain to what degree the design principles are specifically applicable to teachers. However, the articles had to focus on a teacher competency which therefore makes it more likely that the gathered design principles are generalizable to a population of teachers.

Moreover, not all design principles are well supported by the empirical evidence. For example, the article supporting the use of multimodal communication was not trying to answer the question whether multimodal communication was better compared to unimodal communication. This means that this design principle lacks evidence in the shape of being compared with a control condition. The same counts for manageable units which is supported by four articles which make use of this principle, but neither of these four articles' central research question was to provide evidence for manageable units studied in isolation as a design principle.

4.3 Suggestions for further research

Firstly, follow up studies are necessary to determine what makes CMF attractive to use for teachers. For example, it should be determined whether they want to use the system before, during or after giving their lesson. Moreover, which other factors are important for there to be a positive reception of such a system? Maybe teachers would want the CMF system to be available on their smartphones. Therefore, considering the category of system characteristics which influence the willingness to use a CMF system, perceptions from teachers should be taken into account. For instance, it is important to determine at which point in time teachers wish to utilize the system, and whether elaborative delayed feedback is preferable to immediate feedback. Accordingly, a qualitative study using semi-structured interviews should be conducted to gather data on teachers' preferences regarding CMF systems.

Secondly, considering that this review covers new terrain, research should be conducted as to the degree to which these principles contribute to pedagogical competencies of teachers. For example, multimodal communication and manageable units should be researched in the context of teachers utilizing research designs such as a randomized controlled trial. A prototype of a CMF system could be made making use of multimodal communication and manageable units. This prototype can then be contrasted with another prototype system, utilizing an RCT, which incorporates many more design principles in order to distinguish how much the additional design principles add to the efficacy of CMF.

Thirdly, it is important to determine the efficacy of combining every single one of the seven design principles by implementing them into a CMF system, such as a chatbot or an interactive app, and measuring pedagogical skills in teachers. A randomized controlled trial would add to the literature as it would provide evidence for the efficacy of the combined design principles. A field experiment can be conducted to increase the ecological validity, gain insight into the perception of the received feedback, and provide information as to whether the CMF system will be used again.

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