Integration of Cognitive Design Principles with the Connected Mathematics Project Curriculum

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The National Center on Cognition and Mathematics Instruction (NCCMI) aims to apply cognitive principles of learning from the *IES Practice Guide* (Pashler et al., 2007) to the design of a widely-used middle school mathematics curriculum and to test the efficacy of the revised materials. Although the *Practice Guide* provides recommendations based on well-replicated cognitive studies for improving learning and instruction, there is little guidance for how to combine the principles or apply the principles to classroom materials. The integration of principles into an existing curriculum involves the collaboration of cognitive researchers, instructional designers, math content experts, and professional development providers. In this presentation, we will share our methodology for combining cognitive research-based design principles and integrating them with the existing Connected Mathematics Project 2 (CMP2) curriculum.

To create the revised CMP2 materials, the NCCMI has teams devoted to cognition research, mathematics, professional development, and production. These teams work together to ensure that the revised materials are grounded in the research findings, are mathematically accurate and appropriate (in terms of student development and curriculum standards), are clearly specified for teachers, and are produced with a high level of technical quality.

Cognitive Team Revisions: Applying multiple cognitive design principles

The work of our center aims to apply four cognitive principles to the redesign of the CMP2 curriculum. The four principles include: (1) *Visual Mapping*, combining visual with verbal information to promote the integration of concepts, (2) *Worked Examples*, structuring practice by interleaving worked examples and self-explanation prompts with new problems to solve, (3) *Spacing*, carefully spacing the learning of critical content and skills over time, and (4) *Formative Assessment,* using focused feedback on quizzes and homework to promote student learning. The first stage of the process was to determine how our cognitive research teams could integrate their principle-based revisions. Each of the research teams developed rubrics that allow them to evaluate the existing CMP2 materials for compliance with the principles, and the scope of proposed changes were documented. The rubrics enable researchers to identify whether the existing materials met the guidelines of the cognitive design principles, and if not, to specify how the materials would be altered to be in compliance. To communicate the design changes between the teams, the WestEd production team produced a Microsoft Word document that allowed each team to specify proposed changes without the use of advanced graphical layout software.

After the initial review of the materials by the cognitive teams, the center identified the sequence in Figure 1. The *Worked Examples* team took the first pass at the revisions, as their changes focused on the homework portion of each unit and could involve the use of visual representations. Next, the *Visual Mapping* group made edits, and indicated which irrelevant graphics were to be removed, where new graphics should be

created, and when text should be changed to make the mapping between the text and visual information more salient. Finally, the *Spacing* and *Formative Assessment* teams created documents that indicated which prerequisite skills the teachers should assess for, and specified the core knowledge and skills for each unit. Changes driven by one set of design principles that overlapped with other principles were discussed and resolved in biweekly meetings. As needed, the cognitive teams contacted the CMP2 designers to ensure the revised materials reflect the intent of the original curriculum.

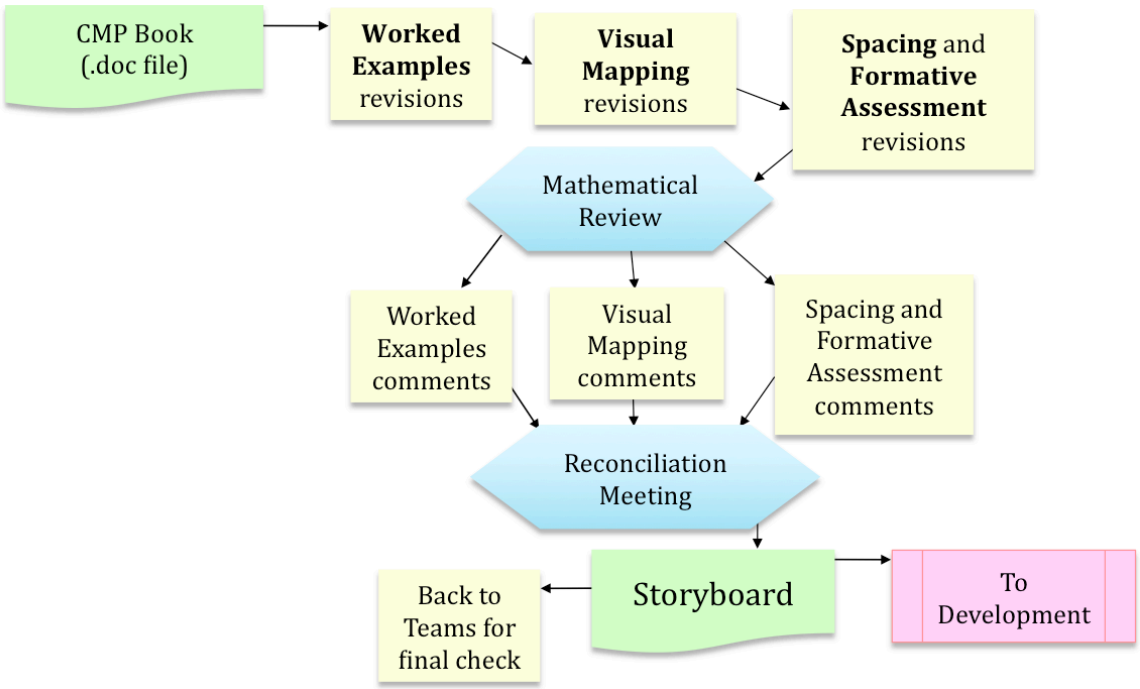

Figure 1. Design Process for Print materials

Math Content Review: Ensuring Mathematical Accuracy and Curricular Coherence

To ensure that our revised curriculum was mathematically accurate and appropriate in terms of student development and curriculum standards, the second stage of the process was a review by mathematics educators that were familiar with the existing CMP2 curriculum. Three external math experts reviewed all materials, and the mathematics team leader produced a report that synthesized the recommendations and suggested changes. The math reviewers suggested changes to avoid mathematical inaccuracies, to ensure that the targeted knowledge and skills in the revisions were aligned with the existing materials, and to identify areas where the revisions may be modified to improve the coherence of the investigations.

As part of the design cycle, the cognitive research teams responded line by line to each of the math reviewers' suggestions and communicated final design decisions to the production team.

Reconciliation Meeting: Ensuring Print Materials Reflect Final Decisions

After the cognitive teams respond to the math reviewers' suggestions and feedback a final meeting is held to establish the final version of the print materials. For the NCCMI, the reconciliation meetings at WestEd involved four people: 1) a math education content expert to ensure the print materials reflect the intent of the math reviewers, 2) a cognitive scientist, to ensure the print revisions reflect the intentions of the cognitive researchers, 3) an experienced mathematics curriculum developer, to ensure changes are in line with professional instructional materials, and 4) the production specialist that will be modifying the graphic design files for production, to ensure all design decisions are fully specified and explicit. After the reconciliation meeting, the production team communicates with the cognitive and math content teams to clarify design decisions as necessary.

Professional Development: The Enacted Curriculum

The final stage of the curriculum revision process is to ensure not only that the print materials reflect research-based design principles, but also that the classroom instruction is true to the principles as well. That is, the print materials reflect only a piece of the instructional experience. The teacher's role is to use the curriculum as a springboard for instruction.

To ensure the curriculum is enacted as intended, the professional development team developed measures of fidelity of implementation and identified effective ways to communicate the underlying rationale and practical implementation of the cognitive design principles to the classroom teachers who will use the redesigned curriculum. All study teachers had at least two years teaching the CMP curriculum (per study requirements), and attended a two day workshop to learn how to apply the cognitive design principles to their work with students. During the workshops the teachers learned about the research behind the principles, identified changes to the curriculum based on these principles, had opportunities to practice applying the principles to their lesson planning and use of the revised units, and learned about research study requirements. Due to geographical constraints, the professional development sessions were offered online in a synchronous professional development model. The workshops were lead by facilitators at WestEd, and teachers actively participated through quick response polls, online breakout sessions, and shared virtual whiteboard spaces. Survey results suggested that teachers felt that the workshops were a good use of their time and adequately prepared them to participate in the study.

Generalizing to other domains

The iterative, multi-layered design process that we have developed for integrating the cognitive principles with the CMP2 curriculum provides a method for putting research into practice. Although our current work is in the context of mathematics instruction, our approach generalizes to bridging research with instructional design across content areas. A multidisciplinary team that includes expertise in the cognitive principles, pedagogical content knowledge educational research in the domain of study, professional development, and instructional designers is critical to ensure that research can be effectively applied to practice.

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