Teachers' Design of Instructional Materials: Locating Teachers' Appropriation of Usable Knowledge

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The phenomenon of teachers designing their own instructional materials is gaining more attention in research. Different aspects of this enterprise have been examined—its potential to reveal the complexity of teachers' instructional planning considerations, the design principles employed by teachers to realise instructional goals, among others. In the study reported in this paper, the focus was on its utility as a form of teacher professional development. In particular, evidence was sought for this claim: not only is teacher-designed instructional materials a useful tool for professional development, it can capture usable knowledge teachers appropriate from professional development.

Introduction

While the study of teachers' interpretation and use of curriculum materials designed by others is an area of intense research for some time now, the focus on teachers themselves as designers of instructional materials for their own teaching is relatively scarce and only emerged very recently. By "instructional materials" I refer to materials that are classroom-ready and intended to be used in the classroom to engage students in learning. Defined this way, curriculum materials (CM) designed by others may indeed be used directly by teachers as instructional materials (IM)—a familiar case is one where teachers 'teach from the textbook'. However, in some jurisdictions, such as in Singapore, it is found that mathematics teachers do not usually use CM directly for classroom teaching; rather, they design their own IM—which may be adaptations of portions of CM—for use in their lessons (Cheng et al., 2021).

In studying teachers' design of their IM for mathematics classrooms, the emphasis has been on elucidating the design principles adopted by these teachers—as a way to understand the layers of complexity in their design processes. But more recently, another perspective has also emerged: the interaction between teacher professional development (PD)—itself an area that generates much interest—and teachers design of their IM (Kaur et al., 2022). The content in this paper is aligned to this new perspective. It is devoted to this particular question: Can teacher-designed IM document teachers' usable knowledge appropriated from PD?

Professional Development and Usable Knowledge of Teachers

One major challenge of PD: how do we do PD in such a way that would result in positive changes in the classroom of the teachers who participated in the PD? This question is borne out of the reality that most PD—even in those where teachers who participated avowed that they have picked up useful ideas—have very little direct impact in changing how teachers conduct instruction in their classrooms (e.g., Hill, 2009; Wallace, 2009). Some have explained this phenomenon using the construct of "inert knowledge" (Renkl et al., 1996)—teachers may acquire some of these from PD but they are not activated during their instructional work. In contrast, "usable knowledge" is defined as "knowledge that teachers are able to access and use in a classroom situation" (Kersting et al., 2012).

This construct of usable knowledge helps us rethink and reframe PD. First, if teachers' usable knowledge is the goal, then how shall PD be done so that the content of PD is about matters that teachers are more likely to activate in their classroom teaching? Yet, this content of PD must remain substantial in the sense that it can effect change in instructional quality—which is the aim of PD. Second, if we can indeed make an argument for such a form of PD that targets usable knowledge,

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how do we prove this claim—that the purported usable knowledge acquired during PD is indeed used by the teachers? At first glance, the answer to the second question seems obvious: "Well, observe the teachers' lessons!" Apart from the reality—as most education researchers would have experienced—that access to classrooms, especially to time the access to be immediately after PD, for all participants is resource-intensive; happenings in the classroom may not be easily traceable directly to PD. Teachers make a myriad of utterances and carry out many activities in the classroom; to make links between these words and actions to those conducted in PD can be likened to finding the proverbial needle in a haystack.

Teacher-designed Instructional Materials in Relation to PD for Usable Knowledge

My claim is that teacher-designed IM can feature prominently in answers to the questions raised in the previous paragraph. The fact that teachers who designed their IM for use in the classroom do so instead of drawing directly from CM means that these teachers want to imbue their personal goals and characteristics into these IM as they are used in classroom teaching. In other words, these IM mirror very closely the chronology and content that actually occur during the in-class enactment of the lessons. That this is so has been reported in other studies (e.g., Chin et al., 2022, Leong et al. 2021). Thus, a careful examination of teacher-designed IM is also a careful examination of the resources the teacher intends to utilise in the classroom enactment that uses the IM. These IMs represent a space where the teacher would consider directly relevant to their in-class instructional work.

This renders IM a suitable object of focus for PD work if the aim of the PD is indeed to influence teachers' usable knowledge. That is, one efficacious way in which PD providers (PDP) can influence teaching quality in the classroom is via the IM that they design, since these teachers follow closely the IM that they bring into their classrooms. When PD revolves specifically around improvements to their IM-design, there is a higher likelihood that learning opportunities during these PD sessions be translated by teachers as usable knowledge since the content of these discourses is about stuff that matters to them in actual instructional work—as reflected in the IM. During these IM-focussed PD sessions, both PDPs and the teacher engage one another not in mere theoretical talk about what may be helpful for in-class teaching; rather, they are engaged in the joint work of realising theoretical ideals into the (re-)design of IM—in a way that incorporates the perspectives of both the teacher and the PDPs. This interaction between the teacher and PDPs that is centred on design work of IM is illustrated in the "PD context" box of Figure 1. During the PD setting, both PDPs and the teacher 'act on' (as shown by the one-directional arrow) the IM in the sense that their talk is directly about contents (and the underlying ideas behind them) in the IM, while they engage one another in the discourse (as shown by the bidirectional arrow between them).

Also, such a form of PD does not start with a 'clean slate' of IM-design; instead, the onus is on the teachers to present the draft of the IM (labelled as IM-A in Figure 1) that reflects their existing conceptions of teaching (a particular mathematics topic) prior to PD. This aspect is shown in Figure 1 as "Pre-PD design". Framed this way, the tone of the PD shifts away from "PDPs imposing their agenda" to that of "teachers retaining their agenda" (Leong et al., 2022). The teacher—having worked through a draft—now comes to the PD session with challenges they would have encountered and are thus more ready to look out for usable knowledge to fill the gaps. And since the PDP's focus during PD is on the IM—congruent to the teacher's agenda, suggestions and ideas will likely then be seen as directly usable for the improvement of IM and thus translatable to classroom instruction. While the PDPs' role is to 'value-add' to the quality of the IM, the prerogative to make changes (or not at all) to the IM rests on the teachers themselves. I think this heightening of the teachers' 'ownership' of the enterprise of IM-design is key to gearing the PD discourse towards usable knowledge acquisition.

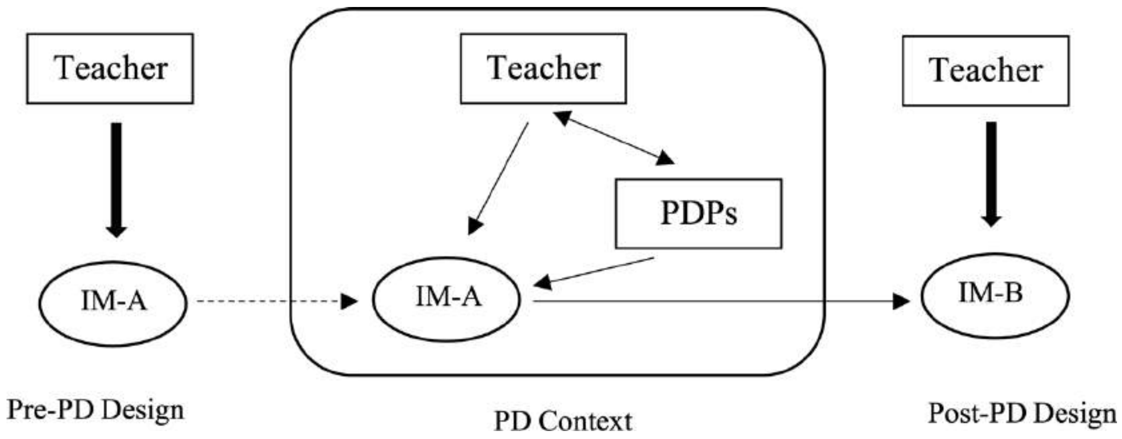

Figure 1. The place of teacher-designed instructional materials in relation to PD.

Following the PD session(s), the teachers work on amendments to the IM in response to the inputs they obtained from the PD setting. The final IM that is indeed classroom-ready is labelled as IM-B in Figure 1. Since there are no known inputs from other sources that are directly focussed on their IM-design between their initial draft and the final one, I claim that the differences between IM-B and IM-A come about exclusively from the PD encounter. In other words, the change in the IM—which is far easier to analyse than classroom enactments—is a reliable proxy to locate usable knowledge as appropriated from PD.

Conceived this way, teacher-designed IM is both a suitable PD resource (as IM-A) and a site to locate usable knowledge gained from PD (across IM-A and IM-B).

Method

The purpose of this study is to explore if the theoretical construction as explicated in the preceding sections of this paper 'works'. That is, when I set up PD—in my capacity as PDP—with teachers as one that is centred on IM-design, and then comparing IM-A against IM-B, do the similarities and differences reveal usable knowledge for teachers that I would consider—as a mathematics educator—an improvement in instructional quality? [This last clause about what "I would consider …" is admittedly a non-rigorous way of judging instructional quality. This study can also be seen as an initial exploration towards establishing standards of instructional quality.]

The study reported here is part of a larger project on "Big Ideas in School Mathematics". The emphasis on teaching towards big ideas in mathematics is a rather recent one which is envisioned by the Singapore Ministry of Education (MOE, 2019). In brief, the push is towards teaching mathematics as connected instead of viewing contents as unrelated bits. As an example, "Equivalence" is highlighted as one such big idea to foreground to students. As students see equivalence as prominent in a number of school mathematics topics (e.g., congruence as a form of equivalence, equality as a special equivalence, equations can be rewritten into equivalent forms), they will then see them as connected by the undergirding big idea(s).

The context of this study is one where I provide PD to mathematics teachers to help them teach towards big ideas in mathematics. This cohered with the set up to 'test' the theory. Five mathematics teachers formed a team assigned by the research school to participate in the PD which focussed on the big idea of Equivalence. One of them, Teacher Benjamin (Pseudonym), was assigned the role to spearhead the design of a set of IM that is suitable for the teaching of the topic "Solving Quadratic Equations by Factorisation" for Year 8 students. Prior to the PD, Benjamin, in discussion with the rest of the teachers in the team, produced IM-A. During the PD sessions—two 1 hour sessions—we discussed many content and pedagogical issues related to the approach reflected in IM-A. In brief, I highlighted specific areas in IM-A where Equivalence can be made more prominent in a useful way for students. In particular, I pointed out that it is useful for students to see that "equivalence of statements" is the basis of typical working steps in the solution of quadratic equations; and it is also useful for students to spot places where such an equivalence is not maintained, resulting in erroneous steps and hence solutions. I offered specific suggestions as to how these can be represented and the locations within IM-A to flag them. After the PD sessions, Benjamin, with inputs from the other teachers in the team, re-designed IM-B. While Benjamin took on a more active role in this whole process as he led in the design and re-design of the IMs, the other four teachers participated in the PD sessions in terms of asking questions and supplying their inputs to changes. The understanding was that they shared in the ownership of the IM. In this sense, the changes in the IMs reflected not only usable knowledge adopted by Benjamin but also potential usable knowledge for the other teachers in the team. That "supporting teachers" can also benefit from such PD sessions with emphasis on just one teacher doing the enactment of the changes—such as in the case of *Lesson Study*—is shown in Leong et al. (2017). In the study reported here, we focus on the usable knowledge acquired by Benjamin.

The data collected were IM-A and IM-B, and the audio record of a post-lesson PD Session. This session was devoted to reflecting on the relevance of Equivalence in the teaching of this topic and the possibilities of extending its relevance to other future topics. There were three steps in the analysis process: The first was to compare IM-A and IM-B, section by section, for surface similarities and differences—inclusion/exclusion of texts, diagrams, or other types of scaffolds. The second step involved pulling these comparisons together to conjecture plausible overarching reasons—especially with respect to the goal of foregrounding Equivalence—for these moves. The last step was to go to relevant sections of the post-lesson PD session to either strengthen or refute the earlier conjectures.

Findings

The surface similarities and differences between IM-A and IM-B are given in Table 1.

The conspicuous change in IM-B is the insertion of equation $x^2 - 3x = 0$ in the introductory section. Note that the students up to this point had no prior experience with solving quadratic equations. It seems that the teacher's intention for this insertion was for the students to experience for themselves the non-triviality of "maintaining equivalence" of each of the solution steps in this case—in contrast to the case of solving the linear equation $1 + 2x = x + 2$ which is but a recapitulation of content that was deemed familiar to students. This experience of 'being stuck' would then provide the motivation to know "Zero Product Principle" in order for the equivalence of statements in the working to proceed. This leads naturally to the next section of explicit teaching of the Zero Product Principle. Concretely, as illustrated in Figure 2, the teacher would have expected the students to be able to keep equivalence between Statement 1 and Statement 2, but knew that the students would not be able by themselves at this point to proceed further to reach the goal of finding the value(s) of x that satisfies the equation.

Table 1

Surface Similarities and Differences Between IM-A and IM-B

Section of IM	IM-A	IM-B
Equivalence	*Problem*: if ab = 0 what can you say about a or b?	*Problem*: Solve 1 + 2x = x + 2 (with about half a page of space thereafter)
	Watch video on Equivalence	[Removed]
	Recall process of solving linear equations as maintaining Equivalence: 2 examples	[Removed]
	Definition of Equivalence	[No change]
	Maintenance of Equivalence is to be continued for solving quadratic equations	[No change]
		Solve $x^2 - 3x = 0$ (with about a third of a page of space thereafter)
Solving Quadratic Equations	Need Zero Product Principle to solve quadratic equations	[No change]
	Arithmetic example: 2 × 0 = 0, 0 × 8 = 0, -3 × 0 = 0, 0 × (-7) = 0, 0 × 0 = 0.	[Blanks are included in some of the Arithmetic example]
	Textual explanation: "If two numbers are non-zero, their product can never be 0 …"	[Blanks are inserted in the textual explanation] added this: "Just like in solving linear equation, we re-write equations into equivalent forms"
	Statement of Zero Product Principle: "If a and b are real numbers such that ab = 0, then a = 0 or b = 0.	Statement of Zero Product Principle: "If a and b are real numbers such that ab = 0 then we can also say its equivalent equations are a = 0 or/and b = 0.
	If P and Q are factors of an algebraic expression such that PQ = 0, then P = 0 or Q = 0"	If P and Q are factors of an algebraic expression such that PQ = 0, then P = 0 or Q = 0"
Exercises	Worked Example 1: Solve (a) $x(x-2) = 0$; (b) $4x^2 + 6x = 0$	[No Change to all the Worked Examples, Discussion, and Practice Questions]
	Practise Questions 1	
	Discussion: Highlight error of dividing by "x" on both sides of the equation for Worked Example 1(b)	More spaces throughout for working for Practice Questions
	Worked Example 2: Solve (a) $(3x+7)(x-4) = 0$; (b) $2y^2 + 7y - 15 = 0$	Given solutions of Worked Examples removed.
	Practise Questions 2	
	Worked Example 3: (a) Solve $25x^2 - 9 = 0$; (b) Explain why $25x^2 + 9 = 0$ has no real solutions	
	Practise Questions 3	
	Worked Example 4: Solve $(2y-1)(y-4) = 9$	
	Practise Questions 4	

$$x^2 - 3x = 0 \text{ --- (Statement 1)}$$
$$\Leftrightarrow\ x(x-3) = 0 \text{ --- (Statement 2)}$$
$$\vdots$$
$$\Leftrightarrow\qquad x = \_\_\_\_\_\_$$

Figure 2. Equivalent statements leading to the solution of $x^2 - 3x = 0$.

The emphasis of this approach is brought into sharper relief when placed against the introductory section of IM-A: the steps taken do not problematise the solution of quadratic equation by factorisation; it is a theoretical definition and explanation of what equivalence of statements mean in the case of solving linear equations and that one needs to maintain this same equivalence of statements in solving quadratic equations. The "usefulness" of this notion of equivalence was not meant to be experienced by the students. In contrast, IM-B was structured not only to explicitise the usefulness of maintaining equivalence as a working means to 'get to' the answer; it was for students to experience the usefulness for themselves—by getting stuck and then find out (through the equivalence of Zero Product Principle) how to be unstuck. In other words, the usable knowledge that Benjamin brought into the design of IM-B was that Equivalence as a big mathematical idea needs to be seen as useful for students in their work, and not merely as a theoretical idea to be 'covered' in teaching.

That this usable knowledge was derived from PD can be summarised by this exchange during the post-lesson PD Session:

3.50. PDP: [Directed at Benjamin]. Do you find [this emphasis on Equivalence] helpful for your lessons?

4.00. Benjamin: It is helpful. Sometimes we say it but writing it [referring to the symbol for Equivalence "⇔"] helps to draw students' attention to it. Sometimes I may not say it, but if I write it, they know they must maintain Equivalence. …

7.07. PDP: From the beginning [of the PD sessions], I say Equivalence must be seen as helpful. If it is not helpful, don't force it. Otherwise, students will just follow and do for the sake of doing which is not meaningful for them. …

9.17. Benjamin: For me, the parts where the equivalence breaks down in the students' method [referring to Discussion, Worked Example 3(a), Worked Example 4] are important in helping them see the usefulness of maintaining Equivalence.

Other evidences which suggest that Benjamin had the intention to lead students to realise for themselves the usefulness of maintaining Equivalence include the blanks and spaces inserted into IM-B—to provide room for students to grapple with underlying ideas related to equivalences instead of direct demonstration of steps by the teacher. This is alluded to in the above extract (at 9.17)—for example in Worked Example 3(a), he expected students' solution to include the step $x^2 = \frac{9}{25}$, then $x = \sqrt{\frac{9}{25}}$, which will give him the opportunity to again emphasise the relevance of maintaining equivalence.

I would say that the change in IM-B did improve instructional quality. By transforming the presentation of Equivalence from a theoretical "you need to know this term and so I have to tell you what it is" to an experiential "Equivalence is what makes the steps work; and without maintaining it, you will realise it does not work", Benjamin used the big idea of Equivalence as consistent language to help students reason through the steps in solving quadratic equations. This explicit foregrounding of Equivalence of equations/statements in this topic is unusual practice among

Singapore secondary mathematics teachers and it is aligned to the ideals of teaching towards Big Ideas in the recent curriculum revision.

Discussion

The claim I made earlier was that teacher-designed IM is a suitable site to locate usable knowledge gained from PD. To subject this claim to a preliminary test, I set out, within the context of a broader project, to engage with teachers in my capacity as PDP using a set of IM designed by Benjamin, one of the teachers who participated in the PD. His first design, prior to PD, was based on how he interpreted the expectation of teaching Equivalence as a Big Idea. During the PD Sessions, the discussions were focussed on the IM. Among other suggestions and elaborations, one thing I emphasised was the need to help students see Equivalence as actually useful for them in the learning of the contents in the topic. There is evidence, based on comparing the first design and the final design of the IM, that this emphasis was accepted by Benjamin and explicitly incorporated into his instructional planning. This comparison of IMs allowed me to locate the usable knowledge he derived from the PD Sessions.

My argument actually goes beyond this claim—into the conditions under which teachers are likely to acquire usable knowledge from PD. Since the IM is designed by the teacher, he has high ownership of the contents in the IM and thus the usefulness of these contents in actual classroom instruction. This renders such IMs a suitable starting place to derive usable knowledge, and using the knowledge to tweak contents therein into forms that are even more usable for teachers—all along without losing ownership of the IMs. Although the data reported here were not crafted to address these other parts of the argument, the observation that Benjamin retained much of the practice items—including their sequencing and development—does not contradict the claim of continual ownership (and hence usefulness of changes made) of the IM throughout the whole process.

The points made in the above paragraphs mean that the setup of teachers' designing of IMs is a potentially fruitful endeavour in at least two ways: as a novel mode of PD that targets usable knowledge for teachers; as a research methodological tool to account for teachers' acquisition of usable knowledge. Each of these would have been considered significant contributions; the two-in-one offer renders it all the more tantalising for further exploration of its potentialities. As methodological tool, admittedly, much more needs to go into the rigorous formulation of an analytical frame to compare the IM development that goes beyond the "surface" comparisons attempted in this report. [The purpose of this report is to show that the IM-comparisons *can* show the location of usable knowledge employed by the teacher]. Clearly, further work must be done to develop IM developmental comparisons into a more robust method of analysis.

But as a school-based PD mode, I think some implications can be derived quite directly here. And so I end this paper with a description of the phases of such a PD mode that the reader may consider translating into actual practice as PDP: (1) Identify the intended additional instructional goal(s)—in the case of Benjamin and his colleagues, it is to foreground Equivalence as a Big Idea; (2) Choose a topic that lends itself easiest to the fulfilment of these goals—in this case, Solving Quadratic Equations; (3) First PD Session to provide motivations for the additional goals and ideas on how it is relevant to the topic at hand; (4) Teacher(s) design a first draft pf IM based on their understanding of these additional goals and in accordance with their own goals of teaching the topic; (5) PD Session(s) that focus on realising the additional goals in the topic using this first draft of IM as concrete materials for discussion. Questions by teachers pertaining to design of the IM are discussed/addressed; (6) Teachers' re-design of IM based on discussions of the first draft of IM; (7) Teachers carry out the lessons in class based on the re-designed IMs; (8) Post-lesson PD Session to clarify and summarise usable knowledge acquired by the teachers throughout the process.

The purpose of explicating the PD phases in greater detail is so that other PDPs may attempt this PD mode and hence open up a whole new domain of inquiry into "Teachers' design of instructional materials *as* professional development".

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