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The impact of COVID-19 on education and children's services

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Summary

The Covid-19 pandemic has made abundantly clear that our school systems are very far from being crisis-ready. The lockdowns recently imposed left schools and teachers scrambling to provide parents with whatever teaching materials they could find that might enable some semblance of distance learning to take place. Despite these heroic efforts, the immediate solutions found are far from optimal. This should not be surprising, since no curriculum anywhere has been designed with school closures in mind. We do not know what the future holds, but it is prudent to plan for contingencies such as further waves of Covid-19, other pandemics, emergencies such as extreme weather events, or even extended periods of industrial action. It is now an urgent design challenge to engineer into our school curricula those features that will allow a school curriculum to function, at least satisfactorily, through limited periods of school closure. We set out here 3 design principles for powerful learning:

- *Make the tasks carry the load*, by choosing substantial tasks that involve important mathematics and provide a cognitive challenge that results in productive struggle for all students at their own level, so that students emerge with a solution that they feel is their own.
- *Develop a student-centred pedagogy*, in which the teacher is treated as a scarce and valuable resource, to be used as an expert back-up to other available resources, notably technology, parent-tutors and friends from the same class.
- *Make technology central, but a servant of the learning* by, for example, using technology to present tasks to the student; offer mathematical tools for standard procedures; and provide 'mathematical microworlds', small and large, to investigate.

We urge a collective endeavour, building on the work of creative designers around the world to: design effective learning activity sequences that will move students/pupils forward toward specific learning goals; and then communicate the design to the user, so they can realize the design in their own classroom.Extensive classroom trialling is the only way to ensure that the designs will be truly effective in practice.

Introduction

Scientists have long warned that it was just a matter of time before a global pandemic caused widespread chaos (e.g., Bostrom & Cirkovic, 2011). Indeed, some have described Covid-19 as merely a "dress rehearsal" for more contagious, even civilisation-threatening future global catastrophes (Greger, 2020). Clearly, no education system can be designed to be pandemic-proof; however, in these uncertain times, with future waves of Covid-19 described as "very real" (BMJ, 2020), it is essential to consider a greater degree of crisis-readiness may be strategically engineered into the curriculum.

In this submission, we take our own area of mathematics as a test case to explore the kinds of strategic re-engineering of a curriculum that would be necessary. Mathematics is important; children get one chance at their education; disadvantaged children miss out the most from any interruption to their schooling (CEPEO, 2020; EEF, 2020) – all of these things are truisms. The cumulative and hierarchical nature of mathematics makes it particularly vulnerable to interruptions to study, yet it is a critical subject to students' overall academic success. Success in school mathematics functions as a gatekeeper qualification to subsequent education, especially in STEM subjects. Leaving school without this can negatively impact a young person's future prospects in employment, economic and social stability, and health and wellbeing (Royal Society, 2016). However, the principles in what follows are more general, at least across STEM subjects.

Emerging research suggests that school closures are detrimental, both through lost instructional time and the forgetting of previous material, and will likely have a negative effect on achievement. Furthermore, students from low-income households may be especially disadvantaged by school closures (CEPEO, 2020; EEF, 2020). A report published only a few months after school closures began suggested that students were already substantially behind, especially in mathematics (Soland, 2020). During school closures, inadequate provision for home learning is widening the socioeconomic achievement gap, with wealthier parents more likely to have the cultural capital, computers and internet connections necessary to support education at home, including affording private tuition. This will have both a short- and a long-term impact on social mobility. The magnitude of this effect will depend on the alternative forms of education accessed during the closures (CEPEO, 2020), and supporting effective remote learning could mitigate the extent to which the gap widens (EEF, 2020).

Drawing on our extensive experience in educational design, we propose practical design principles that could allow future mathematics curricula to be more crisis-ready, so that the detrimental educational impact on students is lessened. We set out what may be possible and what would be needed to put this in place, as well as what the potential benefits could be, both from a crisis-readiness perspective and beyond.

Some responses to school closures

The closure of schools due to the COVID-19 pandemic has caused unprecedented challenges to education systems throughout the world (see NCTM, 2020). Such a dramatic change to the social setting has placed great demands on schools, teachers and family units. In the context of a stressful and rapidly changing international health crisis, teachers are acting heroically by rushing to adapt their materials to digital learning. The sudden requirement on schools and teachers to provide distance learning during the Covid-19 school closures has led to a variety of responses, from live teaching via platforms such as Google Classroom, through assigning questions on subscription websites (e.g. HegartyMaths.com), to teachers creating bespoke narrated PowerPoint presentations (Dawes, 2020). While these are all commendable attempts to provide continuity of provision in a crisis, they are likely to be far from ideal.

In the UK, with £300,000 of initial funding from the Department for Education, the Oak National Academy assembled teaching materials over a 2-week period. These consist of hundreds of 1-hour video lessons from teachers across different subjects, from early years up to Year 9. These free resources have had a mixed reception on social media. As the designers themselves commented (Thomas, 2020):

> "Oak won't change the world. It's not supposed to revolutionise teaching. We just want to make life a little bit easier during one of the most difficult periods in our lifetimes. If we can do that, then it's mission accomplished."

While the materials have been widely circulated, Paul Whiteman, general secretary of the National Association of Head Teachers was not alone in his feeling that the "resources have a shelf-life that should not go beyond the coronavirus lockdown in their current form" [1].

In some ways, the difficulties in resource design during Covid-19 school closures highlight, in an intensified form, wider systemic problems with educational design. Even during normal times, a textbook series is typically written by a group of authors and, after external comments, put together by the publisher under tightly-controlled deadlines that are driven by powerful economic imperatives. This leaves very little time for careful consideration of alternative approaches or detailed analysis of coherence across the entire product, let alone trialling of lessons with real students and teachers in real schools to discover what actually happens. During the writing process, typically, different authors are assigned to different topics or chapters, and editorial control focuses on superficial features of how the pages will look, rather than deeper issues with mathematical didactics. Further, the economic pressures tend to favour a demonstrate-and-practice imitative pedagogy that does not develop autonomous reasoning or non-routine problem solving, but is still dominant in mathematics classrooms worldwide. There are alternative approaches, used in high-performing countries, that have been shown to be effective in developing these higher-level skills.

Design principles for powerful learning

We, the Shell Centre[2] team and its international collaborators have developed over the last 40 years a set of principles for the design of teaching materials whose power is widely recognised (ICMI, 2016). These principles are perhaps best summarised in the five dimensions of TRU, the *Teaching for Robust Understanding* framework developed in recent parallel research at Berkeley (Schoenfeld, 2014, see https://truframework.org/) on the

[1] https://www.naht.org.uk/news-and-opinion/press-room/naht-comments-on-launch-of-oak-national-academy-online-classroom-and-resource-hub/

[2] https://www.mathshell.com/

characteristics of classrooms that lead to powerful student understanding. In brief, the dimensions are:

1. *Content*: Are students engaged with important content *and* processes, bringing out the 'big ideas'?
2. *Cognitive demand*: Do activities involve students in *productive struggle*?
3. *Equitable access*: Are *all* the students actively involved in each phase of the learning activity sequence?
4. *Agency, Ownership and Identity*: Does each student feel that they can contribute their mathematical reasoning, and that it is recognized as "belonging to them" and their fellow students?
5. *Formative assessment*: Is the lesson structured to consistently reveal student thinking and provide formative feedback?

These dimensions, with their focus on the student rather than the teacher, clearly require a different *classroom contract* (Brousseau, 1979) – a set of mutual expectations of students and the teacher as to the roles each will play – that is very different from the more usual imitative learning referred to above. Students take more responsibility for their own learning, explaining their reasoning, not just giving answers, while teachers move from directive to facilitative roles (Phillips et al., 1988). This role-shifting is in harmony with the constraints of remote learning, where the teacher is a scarce resource. It does not, of course, make the design challenges straightforward!

Strategies and tactics for crisis-ready learning

These principles have been realised through the development by the Shell Centre of a collection of design strategies and tactics that help designers to create lesson activity sequences that realise the dimensions of TRU. These have been brought together for classroom teaching and learning, with examples, by Burkhardt and Pead (2020). How might they be modified for home learning? We here offer 3 strategies:

Make the tasks carry the load

The choice of problems that students are asked to tackle is central to curriculum design. This choice should take advantage of the crisis to rebalance the common situation, where much of the mathematics most students learn they neither find interesting nor use in later life or work. Instead, the design goal is to choose *substantial* tasks that involve important mathematics (TRU-1 above) and provide a cognitive challenge that results in productive struggle (TRU-2) for all students (TRU-3) at their own level, so they emerge with a solution that they feel is their own (TRU-4). To this end:

- Choose substantial tasks that kids can 'get on with' at their level for a while (up to an hour) without recourse to adults.
- Make the entry phase of each task easily accessible – e.g., from familiar real-life situations or a game.
- Most tasks should be relatively easy technically, so as to compensate for the strategic and tactical demands that complex and non-standard tasks present.
- To introduce 'harder maths', design tasks in which students can start in 'understand then critique' mode on examples of 'student work' (carefully-designed fictional student responses, see Evans & Swan, 2013), moving on to asking the student to make extensions and engage in tasks such as "Classify and define mathematical

objects and structures", "Represent and translate between mathematical concepts and their representations", "Justify and/or prove mathematical conjectures, procedures and connections" and "Identify and analyze structure within situations" (Swan & Foster, 2018).

- These can be built on and fluency acquired through *études* (Foster, 2018), which allow practice of important skills to take place within a rich, stimulating context, rather than through repetitive routine exercises;
- Connections can be consolidated through modelling problems like "Which of the following situations can be described by this function? Identify the variables and the relationships."

It is central to this approach that there is a *product* of the work of each student or pair of students that is *owned* by its creators (TRU-4), to build on through discussion and review (TRU-5). This may be a report with recommendations, a design or simply an analysis well explained.

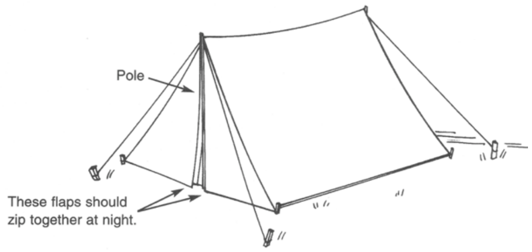
We have space here for just two task examples that have the potential to work well with middle school students and their parents (see Figure 1). The task *Airplane turn-round* gives a list of jobs that need to take place after an airplane lands and before it takes off; how quickly can all of this be accomplished? To begin with, the students typically just add up the times. However, when asked, "Is that really the best you can do?" rich discussions and representations ensue. The task *Design a Tent* asks students to draw up plans for a tent to sleep two adults. No measurements are provided, and students need to estimate appropriate dimensions and work out how to produce the required shape and size. This entails practical, realistic thinking and sensible decision making in a mathematical context.

Airplane Turn-round

- Between landing and taking off, the following jobs need to be done.
- How much time is needed to get all of the jobs done?

	Job	Time needed
A	Get passengers out of the cabin and off the plane	10 minutes
B	Clean the cabin	20 minutes
C	Refuel the plane	40 minutes
D	Unload the baggage from the cargo hold	25 minutes
E	Get new passengers on the plane	25 minutes
F	Load the baggage into the cargo hold	35 minutes
G	Do a final safety check before lift-off	5 minutes

Design a Tent



Show how to cut the material to make a tent like this that is big enough for two adults to sleep in.
Show all your measurements clearly.

Figure 1. Two examples of tasks with the potential to be successful with middle school students and their parents. Taken from https://www.mathnic.org/tools/05_parents.html

Develop a student-centred pedagogy

In home learning, the teacher becomes a scarce and valuable resource, to be used as an expert back-up to other available resources, notably technology, parent-tutors and friends from the same class. However, this shift complements the central need to develop and support student agency (TRU-4). The aim is:

With the parent, to bring out the pedagogical posture, opportunities and responsibility:

- You are not expected to be a mathematics teacher - though you will be in a different way.

- *Learning* is your child's responsibility – give them plenty of time to work on these rich problems before you intervene.
- You won't be 'teaching', mainly asking questions to get *them* to explain their thinking about the task: "Tell me what this problem is about", "What do you think you might try?" – later "What have you tried?", "What did you find out?"
- In every case, ask for more explanation: "I don't quite understand. Tell me a bit more".
- A *Common Issues Table* (see Wake, Swan & Foster, 2016) is provided with each task, stating some specific things that students tend to find difficult with the task – each with some more specific questions you might ask.

With a fellow student. Peer-interactions are a great resource for supporting learning that is often under-used (a relic from notions of 'cheating' on simple exercises). We highlight two modes:

- *Basic mode*: Two students work on the same task in their homes, knowing that they are going to have to explain their approach to a friend, and roughly 'scripting' how they are going to do this. At an arranged time, each explains their approach to the task and what they have found, knowing that they are going to discuss how to make a joint solution that is better. When they have done this, they each write the improved version, then exchange it. They know that the teacher may call on either of them, thus providing a means of formative assessment (TRU-5).
- *Complementary mode*: Here, the two students play different roles, typically one 'making a case', the other 'interrogating the witness' to find holes in the argument. Initially, each student in the pair prepares the case for a different problem and sends an outline to the other; then they take turns at interrogating the other. (Finding meaning in a dataset is a natural kind of task for this mode – but there are others; e.g., devising different ways of organising a knockout tournament).

The roles of the teacher In every classroom, the teacher is the most valuable resource, and a precious one – in a typical lesson a teacher can spend only a minute or two with each student. Finding how best to use this resource is a key element in any curriculum design[3] – and a new challenge for a lockdown curriculum. The teacher's expertise is, first of all, diagnostic – being able to perceive more deeply than a parent or fellow student what a student's approach reveals about their understanding and misunderstandings. The next phase is choosing an intervention that will move a student's thinking about the problem forward without taking it over by being directive about the next phase of the work[4]. The following modes help to best utilise this expertise in a lockdown situation.

- *Sampling mode*: The teachers should be able to sample the progress of each student/pair's work at various points in the thinking process. This sampling will be teacher controlled, though *informed* by end-of-task notes from students and calls for guidance from students or parents. There can be no sense that the teacher is 'available on demand' if their expertise is to be best used.

[3] Standing at the front to explain a new skill, working an example, and then watching the students do exercises, though still prevalent, is far from optimal use of an expert teacher's time or pedagogical skills.

[4] Many teachers are not strong in this 'adaptive expertise'; one of the roles of fine teaching materials is to help them develop it. Common issues tables are a useful part of this.

- *Coaching mode*: From the sampling and prior knowledge, the teacher will judge where significant interventions are needed. These need time and structure to use that time most effectively. So, any given student or pair will not have a discussion with the teacher very often; when they do, they will be expected to discuss the task as fellow mathematicians.
- *'Whole class' mode*: There is a real gain in bringing together a larger group of students (perhaps the whole class) to present their solutions. The teacher chooses an order that shows approaches of increasing sophistication. At the end of each, students may be asked to further develop their own solutions or to tackle a related problem in the light of the discussion.
- *Changeover mode*: At some point, the teacher will judge that the activity sequence for this task as gone on long enough (or, occasionally, has not worked out at all well). If the task has been chosen well, this will normally be after several hours of student work. The teacher will then launch the next task. This may be done for each pair, but there is real advantage in keeping the class as a whole working on the same rich task at the same time.

Roles for technology

Because human aspects of learning are so central, we have left technology to the end of this discussion of resources. But, since communication is such an important part of learning, in a lockdown situation technology must play a central part. The possibilities are endless, but, in education, software is often used to support the elements that *least* need support. Here, we have deliberately avoided specifying what is minimal. Smartphones are now nearly universal in rich countries, and much can be achieved using their camera and voice features alone. With more power, more can be achieved – and with many classes it will be. But a note of caution: the technology should be the servant of the learning; it can easily become the focus instead. Simple uses of a computer's strengths have proved most powerful: presenting tasks to the student; offering mathematical tools for standard procedures, from calculators and spreadsheets upwards; providing 'mathematical microworlds', small and large, to investigate. Attempts to move the computer into analysing student thinking through their responses work for simple tasks but not yet for extended chains of autonomous reasoning (Pead, 2010).

How to get it done

As with anything significantly novel, turning this model framework into a set of high-quality learning materials for a curriculum that is attractive to students, acceptable to teachers and parents, and robust in use is a challenging research and development project. *We envision it as a collective endeavour.* There is a lot to build on: creative designers around the world have produced a wide range of tasks that, in principle, meet the principles set out above (see numerous examples at https://www.mathshell.org/, https://www.map.mathshell.org/, https://www.bowlandmaths.org.uk/ and https://nrich.maths.org/).

Learning units will be of value as they emerge, providing a reasoning-focused complement to whatever is being used. It will take time to build a comprehensive set of materials, but that may not even be necessary – it is unlikely that home learning will last for years. Design will start with simple, low-hanging-fruit – things that could be easily done and will actually enhance the curriculum in most classrooms by improving the balance of types of learning.

The design and development process is an iterative spiral with two phases. It is standard across fields for product development but, since it is so often short-circuited in education, we outline it here.

The design phase of any project has two aspects:

- *Designing* an effective learning activity sequence that will move students/pupils forward toward specific learning goals;
- *Communicating* the design to the user so they can realize the design in their own classroom.

For innovative activities that will take many teacher-users outside their comfort zones, the second is usually the more challenging. To move forward, the design team will need:

- to find, and select with their creators, tasks that seem to: offer easy and inviting student and parent access; lead to important mathematics, accessible at different levels of sophistication; and lead students to develop reasoning that is straightforwardly explicable to parents and the teacher;
- to select from the genres available a learning activity sequence suitable for the task;
- to trial this task with a few students, noting and recording common issues that students have in tackling the task, devising non-directive questions for each issue that parents and teachers can use to move students' reasoning forward without 'taking the solution away from them';
- then, after discussion within the team, trialling it again – rapid prototyping is key to 'getting it as good as we can';
- to combine these elements into three linked guides – for students, parents and teachers – the communicating element, which can only be improved with 'real users'.

The result will be a draft prototype unit ready for systematic development.

The development phase follows the standard iterative process (too rarely used in education) of users trying the materials, the team collecting rich feedback on what happened, and using that evidence for revision of the materials. The elements in the process are:

- *to select a sample* of classrooms that is just large enough to distinguish general features of what happens from individual teachers' idiosyncrasies but small enough to make the next stage affordable – 5 classrooms is often a reasonable target. In the last round of trials, the sample should be reasonably representative of the target group of users – not just enthusiastic, innovative teachers.
- *to collect feedback* on what occurs that is *rich and detailed* enough to inform the next revision – for innovative activities this requires objective evidence either from video or, ideally, for live observation by skilled, well-trained observers, using a structured protocol linked to the design. User-teacher comments are not enough.
- revision of the materials by the team based on the evidence from the trial, aiming to eliminate problems and take advantage of unexpected enrichments. (Introducing significant other changes at this stage is wasteful because it reduces the validity of the trialling.)

This process is costly in time and effort, but, without it, the materials lack research-based warrants for their validity. The goal is to achieve *reasonable convergence* between the observed pattern of classroom activities and the design intentions, which may be modified in the light of feedback.

This intense development phase is later complemented by continued refinement on the basis of post-implementation feedback 'from the field'.

Coherence check As the quantity of material builds up, it becomes necessary to move beyond adding units and to begin to focus on improving the balance of the curriculum to review, classify and structure the emergent learning activities into a rough draft of a coherent curriculum, noting the gaps – particularly in the standard areas of technical skills and their associated concepts.

Cost To develop a full curriculum to these standards will cost a lot of money – but estimates show it as a tiny fraction – much less than 1% – of the running costs of a large education system over the decade or so that it will take (Burkhardt, 2006).

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