IMPROVING EDUCATIONAL DESIGN AND STUDENT LEARNING

What can good educational design achieve, and how?

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Abstract: This paper addresses the challenge of improving the design of educational materials and processes, so that they give typical teachers the support that enables their students to achieve the increasingly ambitious learning goals that modern life has made important – notably in thinking with mathematics about non-routine problem situations as they arise. Having outlined the potential of design shown in other fields, I look at design principles in education and the development process that turns them into effective, robust, user-friendly products. A discussion of the support that teachers need to meet new challenges leads to the roles that researchers can play in this ‘engineering research’ approach. The structure of the argument is illustrated with two brief examples of good design.

1. WHAT DOES GOOD DESIGN MEAN?

In looking for the potential of good design in education, there is much to learn from other fields. So first I will sketch various ways in which high quality design can help.

Good design can make something more widely available and easy to use. There are many examples that have transformed life.

The printing press: Gutenberg’s construction of the printing press made the published book possible, with all that has flowed from that.

The ’Model T’ Ford: In the early years cars were rare, and owned only by the rich. Henry Ford’s first mass-produced car soon meant that ‘almost everyone’ could own a car. This catalyzed tremendous social change.

Computer technology has changed lives in so many, now familiar, ways. (Thomas Watson, head of IBM, famously said that only 3 computers in all would be needed)

In education, we have many examples including, of course, printing. At a basic level, slates to write on, then paper, were big steps from purely oral word-of-mouth education. More recently the individual ‘mini-whiteboard’ allows teachers easily to monitor the responses of a whole class. The design of learning activities that have made a difference range from the Suzuki method for violin playing, the ‘writing workshop’ in English, down to the standard Explanation–Example–Exercises (EEE) mode of teaching mathematics – where a more powerful example is the “lesson study” lessons that fit into the Japanese teaching context well enough to enable Japanese teachers to construct interesting lessons, anticipate student work, etc.

We do not present all these as examples of high-quality design – for EEE, the standard pattern and the limited demand on the teacher surely contributed to its popularity, whatever the limitations of this fundamentally behaviourist approach to learning.
Good design can lead to continuous improvement of familiar things.

The 'Automobile’ The basic design of the car has remained the same for a century – a 'carriage' with an internal combustion engine, transmission, four wheels, the front two linked to a steering wheel; lights, wipers….. Yet the experience of driving a car has been transformed through the continuing refinement of this design in the basics (suspension, steering, braking, seating, engine power, economy, smoothness and noise) in extras (heating, comfort, storage, entertainment, remote locking) and in aesthetics (body design, music systems). From Ferdinand Porsche’s designs to current racing cars we see how many of these improvements begin as cutting edge technology and how, over the course of the years, advances in design make their way into mass production.

Radio, TV and other aspects of electronic entertainment and communication provide other obvious examples of continuous improvements that continue.

Educational materials developed over the last thirty years have shown that we can create teaching materials of familiar kinds that cover a larger range of learning outcomes – including, notably, autonomous problem solving, reasoning and modelling. A comment and a caveat are needed here. Basic research on learning and teaching, linked with more systematic refinement and evaluation in depth, have played an important part in this refinement process. In contrast, it is hard to see any processes in the education system that have been substantially improved – perhaps because they are still rarely based on imaginative design linked to systematic development.

Good design can enlarge the space of possibilities for practice. The last century has seen a stream of life-changing inventions.

The telephone provided a medium of instantaneous communication at a distance, substantially enlarged by the mobile phone.

Search engines have transformed the process of information-finding.

Arthroscopic surgery allows surgical fixes of a wide range of health problems with far less trauma and cost than traditional surgery – itself a revolution in its time.

In education, we have some examples of new possibilities, notably from computer technologies:

Calculators, then graphing calculators, can transform arithmetic – both performance and learning can be substantially improved for most people.

Geometric software (Geometric Supposer, Cabri Geometre, Geometer's Sketchpad) makes an active investigative approach the natural way to approach Euclidean Geometry.

Simulated microworlds, both realistic and fantastic, can provide rich domains for developing investigative skills in mathematics and science.

Computer technology is not essential to profound innovation of this kind. Integrated assessment-teaching-professional development tools, for example, offer a more powerful approach to introducing innovations, using pressure from a new assessment task type in a high-stakes test, and aligned teaching materials for preparing students for the necessary additional professional skills. ("The Box Model" developed by the Shell Centre is an early example, see eg The Language of Functions and Graphs, Swan et al 1986)

Good design can provide existence proofs. Finally, we should note that many design innovations are not immediately taken up on a large scale but play an important role as existence proofs – a seed bank of possibilities for development in a more favourable climate. The concept cars of motor manufacturers point the way to future models. Collective modes of living like the kibbutz are a social example.
In education, we have many examples of existence proofs. For example, 

*High quality assessments* have shown practical ways you *can* test the performances that you really care about, including, for example, the ability to tackle non-routine problems that you have not met before.

*Exemplary teaching materials*, from small units (e.g. Shell Centre 1984, 1987-89) to the American “reform” curricula funded by the National Science Foundation, have shown how typical teachers can deliver student performances involving important high-level skills.

Of course, there is no sharp boundary between these categories. Do car heaters or Google represent a refinement, or a breakthrough? Nonetheless, these ideas can be helpful in thinking about design in education. There is always the challenging question, “How do you ‘go to scale’, turning small-scale exemplars into large-scale impact?”

## 2. EDUCATIONAL DESIGN PRINCIPLES AND STUDENT LEARNING

This is not the place to attempt to review the body of theory (not all of it consistent) based on research on student learning. This theory, like most evidence-based research in education, is focused on improving our *insights* into the processes by which students learn. But insights alone do not directly tell you how to improve professional practice. They do not answer the question “How should I change the way I teach multiplication of whole numbers?”, for example. Design and development are what turn *insights* into *impact*. Theoretically, educational design is a young field.

The theory that is useful to designers consists mostly of sets of guiding heuristic principles\(^1\) like the following, due to my outstanding designer colleague Malcolm Swan (2006):

1. Students do not learn from passively ‘receiving’ information, but through their active participation in social practices, their reflection on these practices and through the internalization and reorganization of their own experience.

2. Students do not arrive in classrooms as ‘blank slates’ but as active learning participants who continually construct extensive conceptual frameworks. These pre-existing frameworks should be recognized and made explicit, not ignored. Pre-requisite knowledge must be activated before new learning can take place.

3. Conceptual frameworks do not develop along pre-determined linear hierarchies. Activities must be designed so as to provide opportunities for students to create their own multiple connections. This will not happen in the same way for all students.

4. The designer’s / teacher’s role is to find / deploy situations and problems that stimulate vivid ‘perturbations’ or ‘conflicts’ with students’ conceptual frameworks to promote re-interpretation, reformulation and accommodation.

5. In order for experiences to promote vivid perturbations / conflicts, learning situations must be so designed to encourage students to recognize surprises and inconsistencies that result from using their own intuitive methods and concepts. Current methods and concepts must be brought to a state of consciousness. If students are not given this opportunity, then ‘foreign’ methods and concepts may fail to be accommodated and become marginalized.

\(^1\) This contrasts with fully developed fields like aeronautical engineering. There the theory of the aerodynamics and the properties of materials enable a designer to design an airplane on a computer that will fly almost as well as the final product. Medicine lies between this and education
6. Conflicts may originate internally, within the individual and externally, from an individual’s interpretation of another person’s alternative viewpoint. Interpretations remain mere ‘shadows’ unless they are articulated through language. (This may involve inner speech as well as exteriorized speech). Social interaction is thus centrally important.

7. Perturbations may only be accommodated if students are able to spend time in reflective abstraction. This necessitates periods of ‘stillness’ (not necessarily silence) when ‘production of answers’ gives way to ‘reflecting on alternative methods and meanings’.

8. Students must appropriate the situations and problems, taking ownership over them, so that they can freely apply and direct their actions and thoughts. Situations must be devolved to students. While this happens, the teacher must refrain from suggesting the knowledge she wants to appear.

9. The teacher’s role is to encourage articulation of intuitive viewpoints, challenge with alternative viewpoints when these do not arise spontaneously (play ‘devils advocate’), and facilitate the reformulation of ideas by mediating learning through language which enables the student to construct his or her own new concepts. This role is pro-active and contrasts strongly with reactive roles adopted in discovery learning approaches. This requires considerable sensitivity on the part of the teacher.

10. To mediate learning, the teacher may provide scaffolding - conceptual resources necessary for a higher level of cognitive functioning. Through interaction the child may internalize these resources as the scaffolding is progressively removed.

11. The teacher should also attempt to foster the institutionalization of the concepts and methods generated by students. The teacher must recognize and give status to students’ own constructions, reveal their inadequacies, seek generalizations and set them beside socially agreed conventions.

Other fine designers have described similar sets of design principles. Others have come directly from design-focused research. Phillips et al (1988), for example, in a study of “using a microcomputer as a teaching assistant” showed the power of role-shifting, in particular of moving students into the traditional teacher roles of explainer, manager and task setter.

As a long-time dedicated observer of designers, I think there are other characteristics at work – for example, the phenomenon of the ‘surprising-but-obviously-right’ (so prominent in Mozart). Above all, the details matter – the following task (by Malcolm Swan, Shell Centre 1987-89) combines these principles with creative detail that surprises and delights.

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2 In a mode that has become widely accessible through the coming of ‘interactive whiteboards’.
Snakes and Ladders

Read the description of the game, then answer the questions below.

This is a game for two players. You will need a coin and two counters.

Rules
- Take it in turns to toss the coin. If it is heads, move your counter 2 places forward. If it is tails, move your counter 1 place forward.
- If you reach the foot of a ladder, you must go up it. If you reach the head of a snake, you must go down it.
- The winner is the first player to reach “FINISH”.

1. Suppose you start by tossing a head, then a tail, then a head. Where is your counter now?
2. List and describe all the faults you notice with the board.

3. DESIGN AND DEVELOPMENT IN EDUCATION: TRADITIONAL V RESEARCH-BASED

In education as in most fields, design skill alone, even when built on the best research and design principles, will rarely produce effective and robust products without a systematic process of development through trialling. Indeed, the more sophisticated the design, the more important is refinement through development. What is involved? To answer this, I will contrast the standard elements in the two main approaches to the development process, which I shall call traditional and research-based.

Traditional approach
The traditional way to develop new educational materials assumes that experienced professionals:
- have sufficient knowledge and ‘craft skills’ not only to sustain ‘best practice’ but to know how to extend that practice to tackle new challenges effectively;
- can pass on their knowledge to other practitioners through explanation, written and oral, well enough to equip them to tackle the new challenges effectively.

This approach is summarized in the box below:

| Traditional Development Model: |
| Write draft materials |
| Circulate to an expert group |
| Discuss at meetings, and revise |
| Publish |

Key features include the absence of specialist designers or any systematic process of development or testing with other user-practitioners. This approach is the way all applied fields (engineering, medicine,...) began. It is inexpensive. It can work well when the system performance is seen as satisfactory but, because it relies on extrapolation with little feedback,
it is unreliable for tackling new and difficult challenges. This methodology raises various questions, notably:

- How reliable is the extrapolation of author's professional experience to the new situation and its needs?
- How effective is the communication of the author's intention to the target community of users?

**Research-based approaches**, in contrast, are characterised by:

- the use of prior research and prior developments, as well as craft skills, to inform design; (This may happen with traditional design)
- specialist designers, chosen for deep knowledge of practice and imaginative design capability;
- an iterative process of development through successive refinement based on feedback from trials in increasingly realistic circumstances, where both the people and the support they receive are representative of the target groups of users;
- continuing evaluation based on feedback from the field to inform potential clients and users of the strengths and limitations of the tools and processes involved.

What this means in practice is outlined in the box on the next page (see Burkhardt 2006). This is a standard process for product development – it is more costly, but more cost-effective.
Research-based Development Model: Development is a systematic process, typically:

The design process produces draft materials. The team has some evidence, albeit with atypical teachers (the authors), on the response of students, but none on how well the materials communicate to enable other teachers to create a comparable learning experience in their classrooms.

Systematic development turns fine drafts into robust and effective products. It involves successive rounds of trials, with rich and detailed feedback, in increasingly realistic circumstances.

Feedback at each stage guides the revision of the materials by the design team. Feedback can take many forms; the criterion for choosing what information to collect is its usefulness for that purpose. This also depends on presenting it in a form that the designers can readily absorb – too much indigestible information is as useless as too little; equally, it depends on the designers’ willingness to learn from feedback, and having the skills to infer appropriate changes from it.

Cost-effectiveness is then the issue, giving different balances of feedback at each stage. In favourable circumstances for, say, the development of teaching materials, these are:

Alpha trials in a handful of classrooms (~ 5-10), some with some robust teachers who can handle anything and others more typical of the target group. This small number is enough to allow observers to distinguish those things that are generic, found in most of the classrooms, from those that are idiosyncratic,. The priority at this stage is rich detailed feedback from each classroom, including:

- structured observation reports by a team of observers, covering in detail every lesson of each teacher (expensive but rich feedback)
- samples of student work for analysis (inexpensive limited feedback)
- informal-but-structured interviews with teachers and students on their overall response to the lesson, and on the details of the lesson materials, line by line (expensive but rich feedback).

Feedback to the designers of what has been found is central to development process, but difficult to optimise. Written feedback and informal conversations are limited, and may lack structure. These can be supplemented by meetings, in which the observers share their information with the lead designer can provide rich and useful feedback. In one model, observers present:

- first, an analytic picture of each teacher in the trials, working without and with the new materials
- then a step by step discussion of the materials, bringing out what happened in each of the classrooms, noting where the materials did not communicate effectively to teacher or students as well as the actual realisation of the intended activities.

The discussion in these sessions is primarily about clarifying the meaning of the data, but suggestions for revision also flow. The role of the lead designer in this process is that of an observer, absorbing the information and suggestions, and integrating them into decisions on revision.

Revision by the lead designer follows, producing the 'beta version'.

Beta trials follow. The priorities are different now, focused on the realisation of the lessons in typical classrooms. A larger sample (20-50) is used. It should be roughly representative of the target groups. (It is useful to have usually obtained stratified, reasonably random samples, e.g. by invitation. "You have been chosen...." has good acceptance rates, particularly when the materials can be related to high-stakes assessment) With given resources, a larger sample means more limited feedback from each classroom, largely confined to written material from samples of students. Observation of the beta version in use in another small group of classrooms is an important complement to this.

Revision by the lead designer again follows, producing the final version for publication. However, this is not the end of the process.

Feedback 'from the field' will guide future developments. Both informal comments from users and more structured research will produce insights on which to build.
4. SUPPORTING TEACHERS

In most systems the teacher is the key link in enabling student learning. So teacher performance in the classroom, the range of skills and strategies they deploy in their work, is a key focus of good educational design. The Explanation–Example–Exercises style of teaching that is standard in most mathematics classrooms worldwide is effective for teaching standard procedures to more able students, some of whom will understand the concepts involved. However, while a century ago these procedural skills guaranteed a well-paid career, human automata have now lost their jobs to calculators and computers. Further, people now need to be able to think with mathematics about problems as they arise in their life and work, if they are to handle the complexities of the modern life effectively.

Teaching non-routine problem solving to students in the classroom is beyond the EEE approach. Most teachers will need substantially to increase their range of teaching skills to include non-standard teaching tactics including:

A. handling discussion in a non-directive way;
B. providing strategic and tactical guidance, rather than showing pupils who have difficulty how to do the problem, or dividing it into pieces;
C. helping students assume responsibility for checking their reasoning and their answers.

Professionals cannot easily change their well-grooved rituals of classroom practice in ways as deep as these, which also imply a profound change in the ‘classroom contract’ (Brousseau 1997). The available research shows that effective change takes time and growing experience based on support of two kinds:

• Well-engineered classroom teaching materials that address the pedagogical issues as well as the mathematical ones. These alone, if well enough designed and developed, can enable typical teachers to make the necessary style shifts – see eg (Swan et al 1986) for A, (Shell Centre 1984) for B.

• Well-engineered professional development support. Much less work has been done on this aspect of design than for teaching materials; the traditional approach still dominates, with leaders of professional development designing their own programmes; yet the nature and scale of the challenge, the shortage of highly-skilled leaders, and the cost of ‘live’ professional development justify a more powerful research-based approach.

This is an area of design that is still at an early stage. Here I shall make only a few points, illustrating them in the session.

• Teachers, like students, benefit from learning constructively – inferring general principles from their own experience of handling specific examples in their classroom, and reflecting on them with other teachers.

• A sequence of such experiences is needed to build an adequate base for constructive generalization.

• Materials-based sessions can provide ongoing professional development in a school between ‘network’ support through, usually occasional, live sessions.

• This needs an acceptance by authority that time is needed outside the classroom to improve their professional skills.

‘The sandwich model’, based on experience–teach–reflect as successive activities, is one robust and effective design for implementing these features. For example:

1. A group of teachers meet together; they tackle a new type of mathematical task (e.g Hurdles Race below, from Swan 1986); prompted by a series of written questions, they discuss the mathematics, how they would handle discussion with students so as to
provide support without ‘taking over’ the task, and what they would expect of a good student response; compose a scoring scheme and apply it to some student papers provided.

2. Each teacher then gives the task to a class, observes how they work on it, handles the discussion more-or-less as they have planned; collects student work ad picks out some exaples for discussion.

3. In the third session, the teachers return to reflect on the questions from the first session, now introducing some work from their own students; they compare their scoring scheme with one that is provided.

This kind of activity usually leads to deep discussions on mathematics, on teaching and on student performance – key elements in professional development.

5. ROLES FOR RESEARCHERS

Is there a role for more conventional insight-focused researchers in the engineering research approach to design and development? There is both a range of important roles in which their skills are needed and important opportunities for them to increase the impact of their work on practice in classrooms – a goal of most researchers.

Engineering research needs analytical research skills at various stages, including:

- structured observation of classroom practice in the trialling process,
- design and analysis of interview and questionnaire responses,
- evaluation in depth of the impact of new materials on classroom processes and student learning, comparing it with the aims of the innovation and with other materials,
- prior research into learning and teaching that has investigated enough variables (students, teachers, designers, …..) to have evidence of what is generic and what specific, and so to inform the principles of design.
This implies a rather different approach to research, and to academic values, than the currently dominant neat, small scale study that yields plausible insights. Such studies, when well done, can suggest interesting possibilities (Schoenfeld 2002) but usually produce no evidence on the generalizability of the insights – an essential for design.

Gathering such evidence requires team projects over a significant time with the replication that is needed to establish the reliability and limits of research results – and regarded as essential in other fields of scientific research. Unfortunately, teamwork, long projects and replication of studies are more difficult to organize and (perhaps because of this) attract little academic credit in the current climate. That needs to change if educational research is to become more than an academic discipline, largely detached from practice.

These issues are discussed in more detail in a paper on *Improving educational research: towards a more useful, more influential and better funded enterprise* (Burkhardt and Schoenfeld 2003) and in Burkhardt (2006).

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REFERENCES


