Educational design and Construction: Processes and Technologies

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EDUCATIONAL DESIGN AND CONSTRUCTION: PROCESSES AND TECHNOLOGIES

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Abstract: There are no one-size-fits-all steps for tackling different design challenges within the context of education. There are, however, processes and activities that are often useful. Developing a repertoire so that designers can select and use the most fruitful and fitting approaches for specific situations is the focus of this chapter. After discussing this phase in relation to those of analysis and evaluation, attention is given to how both analytical and creative perspectives can serve the work of design and construction. The body of the chapter is devoted to presenting specific activities that can be undertaken during design (exploring and mapping solutions) and construction (actually building the solutions). This chapter presents ideas in linear fashion, which loosely approximates the order in which these activities might logically be carried out. However, each design project is different. Not all activities described here are useful in all projects, others are likely to be added, and, several activities described in this chapter often take place simultaneously.

Key words: Educational design, construction, development

1. INTRODUCTION

During design and construction, solutions to educational challenges and problems are created. Solutions can take many forms, including booklets, software, training programs or learning activities. During design, potential solutions are explored and then mapped using a variety of techniques. In this stage, the core ideas underpinning the solution are articulated, which enable them to be shared and critiqued. In addition, guidelines for actually building the solution are delineated. Construction refers to the process of taking design ideas and applying them to actually manufacture the solution. This generally takes place through a prototyping approach, where successive approximations of the desired solution are (re-)built.

Throughout this phase, ideas about how to address the design challenge tend to start off rather large and vague; and gradually they become refined, pruned and operationalized. The work is guided by theory, as well as local expertise and inspiring examples. During design, potential solutions are explored by generating ideas, considering each, and checking the feasibility of ones that seem the most promising. Once a limited number of options have been identified, potential solutions are gradually mapped from a skeleton design to detailed specifications. As the mapping matures, construction of the actual solution begins, usually through a process of prototyping. Early prototype versions of the intervention tend to be incomplete; sometimes several are tested. Later versions are usually more detailed and functional. Table 1 shows the main processes within this phase, each of which is described in the body of this chapter.

Table 1 Main processes of design and construction

Phase		*Step*
Design	***Exploring solutions***	Generating ideas
		Considering ideas
		Checking ideas
	Mapping solutions	Requirements & propositions
		Skeleton design
		Detailed specifications
Construction	***Building solutions***	Creating initial prototypes
	Revising solutions	Revising prototypes

1.1 Positioning design and construction in a larger process

The phrase, design and construction as used in this chapter, refers to work that takes place *after analysis* and *before* evaluation, in a larger development trajectory. During design and construction, a coherent process is followed and documented to arrive at a (tentative) solution to a specific challenge or problem. To do this, the work described in this chapter requires two fundamental inputs, which are typically derived from analysis of the existing situation and stakeholder concerns: (1) a clear problem statement, which describes the challenge to be tackled and explains the reasons why the challenge exists; and (2) a long-range goal. These inputs are essential to focus the work of design and construction, and also form the criteria against which solutions will be later be evaluated.

The design and construction process can lead to several outputs. Exploring and mapping potential solutions can yield documents that describe potential designs to be created. These can range from broader descriptions of the skeleton design, to more detailed design specifications. The construction process yields the solution itself, which may lend itself to actual representation in a physical form (e.g. a teacher guide, educative software) or indirect representation (e.g. process guidelines for a particular approach to teaching). Any of these outputs can be the subject of evaluation. For example, field-testing or expert appraisal may take place to ascertain and improve how well the long-range goal is (being) met.

1.2 Analytical and creative mindsets

The design and construction of teaching/learning resources, websites, activities and programs is systematic and intentional, but also includes inventive creativity, application of emerging insights and openness to serendipity. In other words, the work is served by both analytical and creative perspectives. From the analytical side, it is necessary to weigh off the quality of ideas being proposed, to seek ways to make solutions rational and practical, and to keep a steady focus on the long-range goal. From the creative side, weird and out-of-the box ideas may be needed, this may require pushing commonly accepted boundaries, and tinkering to ascertain what is really possible (or not). Taken together, the activities presented here might aptly be described as what Walt Disney called “Imagineering.” Disney visionaries use this patented term to describe the master planning, design, engineering, production, project management, and research and development undertaken in their creative organization. We find the blend of the words imagination and engineering useful to emphasize the need for both creative and analytical viewpoints throughout educational design initiatives.

2. HOW TO DESIGN

2.1 Exploring solutions: What shall we design?

As mentioned previously, prior analysis yields several products that provide starting points for design: a problem statement which is both descriptive and explanatory, and a long-range goal. For example, a descriptive problem statement could be: *Teacher use of technology frequently constitutes mere replacement of existing (less complicated and expensive) materials, and sometimes even a decrease in the quality of learning interactions; only one of every eight middle school teachers in this district uses the tablet computers provided to them and their students in ways that are transformative with respect to how instruction is planned, implemented, and evaluated.* Explanations for why this situation exists could come from literature, e.g.: *It is well-documented that teachers struggle to align technology use in general and tablet use in particular with other dimensions of their lesson planning (e.g. objectives, instructional activities and assessment).* Additionally, explanations may come from previous investigation, which revealed that: *Several teachers are disinclined to learn how to integrate the tablets because colleagues at another school in the district have reported unfavorable experiences*, and/or: *Half of the teachers are concerned that the time needed to integrate the tablets will distract from instructional preparation for high-stakes tests; and they worry that their students would not perform well on these assessments,* and/or: *Technical issues such as recharging the tablets and breakage are a major concern for teachers*.

In some cases, the ultimate design goal may relate closely to the original problem statement. For example, related to the situation above, the long-range goal of the project may be: *To have all of the district's teachers sufficiently knowledgeable, comfortable and confident in using tablet computers in ways that move instruction from a teacher centered model to a learner centered model*. In all cases, it is sensible to ensure that the descriptive and explanatory statements are clear and accurate before commencing design and construction.

Idea generation

Once the problem statement and long-range goals are clear, the first step in design is to generate ideas, often called *ideation*. The most common approach to generating ideas is brainstorming. In brainstorming, ideas are spawned with the intense burst of a storm, the wilder the better. Building on ideas is encouraged, and judgment is to be reserved for later. It is often useful to start off with a brief warm-up, maybe involving a humorous element, to set the mood. For example, free association can stimulate the imagination. In free association, symbols or words are either written or spoken. Starting with one word/symbol either written for all to see or spoken aloud, each person draws/writes/speaks the first thing that comes to mind. Below are some useful techniques for enhancing brainstorming.

- **Synectics**: Rooted in the Greek word *synectikos* which means "bringing forth together," this technique stimulates new and surprising ideas through (sometimes outrageous) analogies, prompted by a question like, "If your course on statistics were a television show, which one would it be and what would it be like?"
- **SCAMPER**: Asks questions to generate additional ideas from an existing list, prompted by each word in the acronym SCAMPER: Substitute (e.g. Different ingredient?); Combine (Combine functions?); Adapt (e.g. Can this be like a previous idea?); Magnify/modify (e.g. Grow? Add?/Change?); Put to other uses (e.g. Repurpose?), Eliminate (e.g. Simplify?); Rearrange/reverse (e.g. Shuffle?/Transpose?)
- **Slip writing**: People write ideas on slips of paper and pass them around; ideas are changed or augmented along the way; contributors may be named or anonymous; the same or a different group sorts and evaluates the ideas.
- **Picture taking**: Using (cell phones with) digital cameras, participants leave the meeting area to take pictures of novel or familiar objects from creative angles, the more unusual the better; projected images are then shared with the group, who engages in free association and then uses the associations as starting points for new ideas.

Other techniques for idea generation tackle the process in a more analytical and systematic manner. For example, based on a clearly specified design goals and requirements for the solution, a morphological chart can be employed to list solution functions and solution components. It can be used in either direction, but is most often helpful when taking big ideas and operationalizing them into specifics. The usefulness of this technique hinges on the quality of any initial design ideas the team already has. This technique is thus usually more useful once after initial brainstorming has taken place. Table 2 shows a sample morphological chart. The chart was developed in response to the question, "Given your understanding of the failure/drop-out problem in this master's program, what are potential solutions?" Similar to distinctions given elsewhere in educational design literature (cf. Linn, Davis, & Bell, 2004; McKenney & Van den Akker, 2005), it shows design propositions of three grain sizes: broad (dark grey), mid-level (medium grey) and specific (light grey).

Table 2. Sample morphological chart

Broad propositions	Mid-level propositions	Specific propositions (multiple options)		
Clarify real world relevance	See career opportunities	Invite guest speakers	Use real cases	Show job postings
	Motivational	Concrete tasks	Fun tasks	High yield projects
Develop improved planning skills	Address study and time mgt.	Offer reading and note-taking tips	Explain about time budgeting	Teach backwards mapping
	Adjustable pace	Reading	Guided self-study	Individual work
	Offer practice opportunities	Mini-thinks to apply study skills	Exercises during classes to address study skills	Map week, month and semester planning
Foster student relationships	Encourage interaction	Buddy system	Poster fair, online forum	Team prepared presentations
Clarify personal growth	Feedback	Expert-coaching	Peer-review	External review
	Reflection	Journal	Presentation	Videotape

Tip: Supportive software for *generating ideas*
=> Concept mapping tools like MindMan, Inspiration or MindMaple

Idea consideration

Once ideas have been generated, the next task is to sift through, consider and judge ideas, to identify the one(s) that has the power to live on. During idea consideration, critical thinking is essential. Critical thinking is greatly enhanced when a robust set of conditions or boundaries into which the design must fit. Ideas that cannot work within those will be discarded, and feasible approaches will be compared in terms of their risks and benefits.

There are many ways to compare potential solutions to problems. Four techniques that are often useful to stimulate critical thinking are:

- **De Bono's hats**: Participants take turns considering ideas from one of six roles, each of which focuses on different aspects: White hat – facts & information; red hat – feelings & emotions; black hat – being cautious; yellow hat – being positive and optimistic; green hat – new ideas; blue hat – the big picture. Considerations are captured aloud or on paper.

- **Courtroom challenge**: The two best ideas are represented in a mock courtroom. Their 'cases' are made by opposing teams, who try to convince the judge that one is superior (or guilty/not guilty of a particular design flaw).
- **Strengths/weaknesses matrix**: Design requirements, are listed vertically, and design options are listed horizontally. As the matrix is completed, each design option is ranked in terms of its perceived ability to meet each criterion. Rankings can be +/-; +++/---, numerals, happy/sad faces, etc. When numerical rankings are used and tallied, this is called the Pugh method.
- **Weighted ranking**: This is an extension of the strengths/weaknesses matrix, in which each of the criteria is given a weight of importance. A design that scores equally well on 'cost' and 'reliability' will have a higher score for 'reliability,' if the feature of reliability has been weighted as more important.

While decision-making is fed by rational, analytical perspectives, such as those generated using the methods above, these perspectives do not drive the endeavor alone. As stated before, a limitation of some of the more systematic approaches (e.g. weighted ranking) is the quality of the design requirements being used. If decisions are made based only on what is known, there is a risk of overlooking the fact that educational designers cannot know everything. There should be a voice of instinct, intuition and positive thinking. Also, decision-making (in initial design or later) will rarely involve consideration of one factor at a time. Very often, trade-off decisions will have to be made (e.g. the most effective option is not very feasible; the ideal scenario is insufficiently practical; the practical option might not be effective enough, and so on).

Tip: Supportive software for *considering ideas*
=> Spreadsheets and table-making tools like GoogleSheets, Excel, Word

Idea checking

Once a limited number of ideas have been deemed worthy of pursuit, it can be useful to check their inner logic and potential viability in the target setting. This entails comparing the new ideas with what is already known about the reality of the situation, including the people involved. To facilitate the comparison process, it can be helpful to map out how a particular intervention is intended to work, by explicating its underlying assumptions. One powerful way to do this is through the creation of a logic model. Logic models describe inputs, processes, outputs and outcomes of an intervention. While logic models can be developed at various stages in the design process, they are often most useful after a potential solution has been decided upon and before it has been mapped or constructed.

Logic models depict the solution and its outcomes, showing the assumed 'if-then' relationships that yield the desired outcomes. As such, they represent the theory of change underlying an intervention. Logic models portray inputs (including, but not limited to, the designed intervention), processes (implementation of the designed intervention), outputs (evidence of implementation) and outcomes (benefit or change that results). Logic models can be basic, showing the four elements described above, or elaborate, depicting great detail or additional influences on the intervention, such as contextual factors. There are many formats and templates for logic models, showing relationships and feedback loops, with varying levels of detail and even nested layers of concepts. Table 3 shows an example of a logic model for an intervention that aims to develop teacher sensitivity and ability to meaningfully engage with children in multi-cultural classrooms, with the overall goal of improving pupil learning gains during collaborative projects. Additional resources and information about the logic modeling process are available online and in print (Kellogg, 2004; Mayeske & Lambur, 2001).

Table 3. Logic modeling template and example

Inputs	**Processes**	**Outputs**	**Outcomes**	**Impact**
What is needed	*Activities*	*Immediate results*	*Effects*	*Measurable change*
▪ Lesson materials ▪ Teacher awareness ▪ Pupil motivation ▪ External expertise ▪ Financial support ▪ Cultural expertise	▪ Hire facilitators ▪ Develop materials ▪ Professional development ▪ Awareness campaign ▪ Secure grant	▪ Number and description of: ○ Materials made ○ Facilitators hired ○ Workshops held ○ Teachers trained ○ Children reached	▪ Increased educator sensitivity to cultural differences ▪ Improved climate of multi-cultural classrooms ▪ Higher learning results on collaborative projects	▪ Substantial differences reflected in pre- and post-intervention data from: ○ Teacher interviews and questionnaires, ○ Classroom observations and ○ Pupil assessments

Tip: Supportive software for *checking ideas*
=> Visualization tools for flow charts and diagrams, like draw.io, lucidchart, gliffy

2.2 Mapping Solutions: When fundamental understanding is applied

Refining design requirements and design propositions

To start mapping out the chosen solution, a first step is to reflect on and articulate the design requirements and design propositions. Design requirements are criteria to which the design must adhere, like *"the design must require only the materials found in a typical classroom environment or brought in for virtually no cost," or "the design must require only basic operations of a tablet as pre-requisite knowledge,"* or *"enactment/use of the design must fit within the normal school day and not require additional class or preparation time."* Typically, design requirements pertaining to boundary conditions, opportunities and constraints that would have been identified in a previous phase of analysis. But now that the solution is known, it may be necessary to gather additional inputs from an(other) analysis. For example, if the solution chosen is technology-based, but no data on technology infrastructure, attitudes toward technology use, or technological expertise and support were initially collected, literature may give some guidance, but it would probably make sense to revisit the field to learn more about such aspects in the context in question.

In contrast, design propositions suggest how things can be done and why. For example, *"the design should be web-based, because this allows schools with varied technological platforms to access the materials"* or ***"****Teacher workshops should be tailored to take place during one of the two regularly scheduled monthly team meetings."* Design propositions are typically generated through literature review, discussion in the team and discussion with stakeholders. During the literature review, questions are posed and answered concerning the overall solution and/or its key ingredients (e.g. *What are effective strategies for increasing learner engagement?*). In educational design literature, many terms have been used to describe the integrated, theoretical underpinnings for design, such as conjectures (Sandoval, 2004), principles (Linn et al., 2004), and frameworks (Edelson, 2002).

Design requirements and propositions help sharpen the focus of an intervention and provide solid grounds upon which design choices can be made. When captured, they also help to document and track the evolution of design insights. Earlier requirements and propositions tend to be more sketchy and written for internal audiences. Careful establishment, articulation and refinement of (integrated) design considerations, followed by empirical testing, can inform the work of others. For example, building from ideas about teacher pedagogical content knowledge, Davis and Krajcik (2005) presented a set of design propositions (they use the term, heuristics), to further the principled design of materials intended to promote both teacher learning and student learning. As another example, Edelson (2002) presents an integrated set of design propositions (he uses the term, framework) for designing technology-supported inquiry activities.

Tip: Supportive software for *requirements and propositions*

=> Tools can help identify and save guidelines and inspiration, such as referencing software (e.g. Endnote, Mendeley) and visual bookmarking (e.g. Pinterest, Tabs Outliner)

Skeleton design

As described above, design requirements and design propositions are first articulated so they can be critiqued and elaborated. Next, these ideas are put to use when potential solutions are mapped. This is generally a gradual process, which starts off identifying the main lines, or skeleton of a solution, and increasingly fleshes out details. Constructing a skeleton design is important because it helps designers identify core design features and distinguish these from supporting ones. As the design and construction process ensues, the temptation for 'feature creep' increases (i.e. adding features to the design that were not originally planned). The skeleton design, along with design requirements and design propositions, can help weigh the costs and benefits of proposed additions.

There is no set format for a skeleton design, but generally, attention is warranted to at least: materials/resources; activities/processes; and participation/implementation. Materials/resources include the physical artifacts that will be part of the intervention. Activities/processes describe the main events through which the intervention will be carried out. Participation/implementation gives additional detail on how actors will engage during those events. Through the skeleton design, it should be clear which components are new, and which components, if any, already exist within the target setting. For example, the skeleton design may mention that teacher meetings will be held. It should also specify if those meetings are separate from, or integrated into, regularly scheduled ones. Table 4 gives examples of the kinds of content areas addressed in the skeleton design.

Table 4. Five examples of content areas to be elaborated in a skeleton design

Design task	**Materials/resources**	**Activities/processes**	**Participation/ implementation**
In-service program	Worksheets Guidebook Workshop agenda Videos	Expert coaching Peer observation Workshops	Individuals (coaching) Pairs (observations) Groups (workshop)
After school science program	Science toolboxes Workbooks Facilitator guide	Children conduct semi-independent inquiry activities	Children (groups) Facilitators (individual)
University level course	Reading lists Online lectures Discussion threads Assignment descriptions Assignments Exam	Online lectures Face to face working group meetings In and out of class assignments Take exam	View lectures out of class Small group in class meetings Individual and pair assignments Individual exam
E-Learning environment	Software User guide Informative website	Teacher meetings On-computer activities Off- computer activities	Meetings in teams Children do on- and off- computer activities during regular class time
Curriculum materials	Printed booklets Worksheet masters Digital tutorials	How-to courses	Individuals and teams of teachers Administrators

The skeleton design may also indicate the scope of the project, defined primarily in terms of goals, people, time and budget. Linking the long-range goal to specific components in the design can help establish and maintain focus. Often, writing and re-writing the project goals succinctly helps researcher/designers to separate out long-range and interim goals. The people bearing mention in the skeleton design can include the target group, the researcher/designers, experts and additional stakeholders, who will, directly or indirectly, be involved in creating or implementing the design. Timelines should indicate the start and end of the project, as well as the anticipated flow of the project, indicated by milestones. A cautionary note: project timelines tend to be chronically over-optimistic, with the (re)design and construction phase usually being the most drastically underestimated.

Finally, the budget indicates the anticipated project expenditures. It usually provides an estimate of people hours and material costs.

Skeleton designs are generally created for internal audiences only, although they may be described for external audiences in project proposals. They can be used as a kind of organizer for identifying components that require further specification. Before doing so, it may be useful to evaluate the skeleton design. Feedback (e.g. through expert appraisal) on a skeleton design could crush or affirm initial ideas or, more likely, refine them. Taking the time to refine skeleton designs can save valuable resources that might otherwise have gone into detailing ill-advised components. If not subjected to formal appraisal, the skeleton design should at least be checked for alignment with the design requirements and design propositions.

Tip: Supportive software for *skeleton design*
=> Tools to capture (collaborative) sketching, drawing and outlining, like Digital Camera, Cosketch, Flockdraw, a Web Whiteboard, Webspiration, Quicklyst, Knowcase

Detailed design specifications

Once the skeleton of a design has been set, it is necessary to further specify aspects of the entire intervention, and/or of specific components of the intervention. This may happen in one fell swoop, but it is usually a more gradual process, eventually resulting in detailed design specifications which provide the information needed to begin crafting the intervention. There are usually clusters of ideas about the substance of the intervention (the design itself), as well as the design procedures and processes (how it gets created). If design is compared to cooking, substantive specifications describe the finished cake in careful detail, so well that the reader ought to be able to imagine it quite clearly. Procedural specifications, on the other hand, are like the cooking steps in a recipe. For example, substantive specifications for educational software will likely describe the content, learning supports and interface design. This might include screen mock-ups, with comments printed in the margins, highlighting certain aspects or describing certain functions. Procedural specifications for educational software will likely include timing of developer team meetings, indication of how often and through which mechanisms feedback is collected, procedures for making revision decisions, and so on. As with the skeleton design, it is strongly recommended to evaluate detailed specifications before commencing with construction. Here too, even if not subjected to formal appraisal, the detailed design specifications should be assessed for alignment with the design requirements and design propositions.

Tip: Supportive software for *detailed specifications*
=> Collaborative, hyperlinked media like GoogleDocs, DropBox, FirstClass

3. HOW TO CONSTRUCT

After solutions are designed (above) specific components of the actual intervention are constructed. For example, the worksheets needed for a learning activity are made; the agenda for a teacher workshop is drawn up; or the pages of a website are created. Returning to the culinary metaphor above, construction is akin to the act of cooking (as opposed to meal planning, which is more similar to design). We like this metaphor because cooking, like powerful educational design, is best served by a blend of systematically planned action (based on sound knowledge of the ingredients), and creative inspiration at the time of concoction.

Supportive software for *constructing solutions*
This varies highly as it is dependent on the specific solution envisioned (e.g. word processing software for documents; video-editing software for clips and movies; html editors for websites; or social networking services for awareness and implementation campaigns. Regardless of the final medium used, simple interim technologies are sometimes helpful for creating initial prototypes (e.g. PowerPoint slides can be used to mock up a user interface). Prototyping is discussed further in the next section.

3.1 Building initial solutions

Prototyping has traditionally been associated with engineering and is a well-established, systematic approach to solving real-world problems in many fields, including education. For example, Newman (1990) described a process he calls formative experiments for exploring how computers can be integrated into classrooms. Reinking and Watkins (1996) describe how a series of experiments was conducted to both investigate the effects of, and to redesign, a unit to promote independent reading of elementary students. Nieveen (1999) describes a prototyping approach based on consecutive formative evaluations, along with the framework that was used to evaluate three different quality aspects of those prototypes. This section describes what is meant by prototypes in educational design and the forms that they may take. Suggestions on how to orchestrate the prototyping process and prototype in teams are also provided.

Prototypes in educational design

The term, 'prototype' is used to describe draft versions of the *constructed* solution. During construction, many detailed decisions must be made. These are largely steered by the design requirements and design propositions; and guided by the skeleton design and detailed design specifications. However, since it is virtually impossible to specify every single detail ahead of time, a substantial number of design decisions will be made during actual construction. As such, construction typically ensues in phases, and not all at once. NB: While the design ideas mentioned above (requirements, propositions, skeleton design, detailed specifications) do go through iterative refinement, they are not considered prototypes, because they represent the *planned* solution, not the constructed one.

Prototypes can encompass a wide range of artifacts, such as software, books, websites, and so on. While some parts of the solution cannot be created ahead of time (e.g. the interaction that occurs during classroom enactment), prototypes can be made directly for some components (e.g. learning resources or written policies) and indirectly for others (e.g. tools that guide classroom routines or program structures). Examples of components that can be prototyped include:

- Product component (direct): Semi-functional learning software
- Policy component (direct): Organizational documentation or memo
- Process component (indirect): Guidebook for teachers to plan, enact and reflect on their own lessons
- Program component (indirect): Agenda and activity descriptions for school leadership development

Forms of prototypes

Prototypes range from partial to complete components of the desired solution. They often contain samples of what the finished product might look like; and they may exhibit 'functional' or 'dummy' features. For example, a visual prototype of a software program can be created in PowerPoint, just to illustrate the interface design, and operationalize the 'look and feel.' It might be done for the entire program, or for several components. Different forms of prototypes have been identified in literature, including**:** throw-away; quick and dirty; detailed design; non-functional mock-ups, and evolutionary (Connel & Shafer, 1989). For example, a paper prototype of a software program would constitute a non-functional mock-up.

There are several ways in which initial prototypes differ from more mature ones, and these are represented as a continuum in Table 5. First, the components that are elaborated in early prototypes generally do not represent all elements of a solution. This is often intentionally done (e.g. "we wanted to pilot the first module before developing the whole series/course/program"); but not always (e.g. "once we began prototyping, we realized we had to build in a whole new section with support for second language learners"). Second, prototype functionality tends to increase over time. This is particularly common for technology-based interventions. Third, prototype components gradually transition from temporary versions to more enduring ones. Earlier on, it can be much more sensible to throw-away (pieces of) the prototype (e.g. distracting features in an interactive learning environment; activities that did not function as anticipated); but as approximations of the desired solution become increasingly successful, more and more of the solution becomes stable. Rather than starting over or trying new alternatives, refinements are made to a solution (e.g. interface tweaks; re-sequencing learning tasks), the essence of which remains constant while detailed fine-tuning and embellishments continue over time.

Table 5. Maturing prototype features

As intervention matures, prototypes grow and stabilize →

	Initial	**Partial**	**Complete**
Parts elaborated	One or few components	Several components	All components
Functionality	Mock-up	Semi-working	Fully working
Permanence	Throw-away	Mix of throw-away and evolutionary elements	Evolutionary

An example of prototyping in educational design is described by Williams (2004). She explored the effects of a multimedia case-based learning environment in pre-service science teacher education in Jamaica. Her dissertation provides a detailed account of both the design and formative evaluation of the prototype learning environments, and the effects of its use on pre-service teacher learning. Williams' design and development account clearly described how design propositions related to cooperative learning were initially conceived and integrated into three prototypes of the learning environment, before arriving at a final version. The description also addresses how empirical findings and other considerations prompted revisions in prototypes of the tool.

How to manage prototyping processes

The range of solution types that could be constructed is vast. It is therefore impossible to address them comprehensively here. Instead, attention is given to orchestrating the process. The prototyping process may be accomplished by individuals, working with a sketch pad or a computer. But teams can also build prototypes, sometimes using computers but often using pens, posters, or large display boards to create mock-ups.

It is possible, though not so likely, that the design endeavor will feature the development of one, single, prototype component. But given the interventionist nature of design, it is more likely that several components of a solution will be prototyped. For teams, but also for individuals working on design, it is quite common for development of different components to be going on simultaneously. For example, in developing a technology-rich learning resource for a university level course on geometry proofs, prototype components could include lesson plans, an on-line proof tool, learner assessments and a workshop with teachers. Overseeing all this requires masterful orchestration.

Being able to see the project like a jigsaw puzzle and plan for the construction of its constituent parts is extremely helpful. Many strategies and tactics that apply to generic project management can be useful during the prototype development in educational design. For example, project management reminds us to pay careful attention to how our resources are allocated. An over-allocated resource is one that has more work demands than the time frame allows. We often find that designers (especially teachers and graduate students) could be well described as over-allocated resources. This should give pause, as over-all project productivity is threatened when resources are over-allocated. Below, several tools are described to help with orchestrating design prototyping.

- *Critical path:* Flow-chart style representation of main activities (elaborate ones include supporting activities), where bold lines indicate essential tasks and trajectories, and thin lines represent preferred, but not required, tasks and trajectories.
- *Gantt chart:* Convenient, straightforward, two-dimensional overview of project development and supporting activities, with components shown vertically and time shown horizontally.
- *Milestone map:* Target dates for completion of certain elements, which can be listed separately or integrated into a Gantt chart.

- *Rasci matrix:* Clarifies roles and responsibilities in projects as those who are Responsible (who does the work, often the lead designer), Accountable (who is ultimately accountable for thorough completion, often a PI or graduate supervisor), Consulted (with whom there is two-way communication), Supporting (who helps the person responsible, like a research assistant) and Informed (who are kept up-to-date on progress through one-way communication, like funders).

Tip: Supportive software for *managing prototyping*
=> Many books and electronic tools provide insightful and practical support for project management. Microsoft Office Project and the online tool Basecamp are two widely used electronic tools for project management.

Prototyping in teams

Aside from lesson planning, few educational design projects are undertaken as a one-person show. Most successful design projects involve varied expertise on a (multidisciplinary) team. Yet even in the case of projects undertaken by a single individual, there will be moments when additional expertise is needed. In some cases, outside experts will actually construct elements of the design (e.g. a computer programmer builds software). In other cases, project collaborators will co-construct design components (e.g. teachers and designers collaboratively plan lessons). And still other elements will be created by the core project members themselves with critical input from outside experts (e.g. subject matter specialists give guidance or examples). In addition to the project management techniques listed above, it can also be useful to create a document that plans and tracks who is creating what, and the envisioned timeline from start to completion.

Each project demands its own range of specific expertise. In educational design, it is common to seek out expertise related to the media being used, the content being addressed, the intended pedagogy and those with a strong sensitivity to what may be accepted in the target setting. Media experts include those who put prototype components into publishable form, such as desktop publishers (some clerical staff members are wonderful at this), software developers (ranging from hobbyists to professionals) and website designers (many institutions have these people in-house). Content specialists include subject matter experts, who often work in research, practice or both (e.g. faculty in a university department of mathematics education often conduct their own research and supervise teaching practice). Pedagogy specialists may also have more of a background in research (e.g. researching the use of serious games as a learning strategy) or practice (e.g. a corporate trainer with expertise in adult learning). Many experts will possess a combination of specialties (e.g. pedagogical content knowledge experts specializing in inquiry learning in science). It is extremely useful to have practitioners on the design team, with their sensitivities to the affective and practical aspects of the target context being high among the many contributions they can make to a design team. Practitioners often help ‘keep it real’ by being able to voice interests and concerns that are likely to be shared by others, and determining what is (or is not) feasible, in the target setting. For educational designers working in or from a university, it may be possible to expand project resources at little or no costs by providing internships or learning opportunities to students from other types of programs. For example, students from graphics design courses might be able to produce artwork for e-learning environments and students in computer science courses might be able to do initial programming.

3.2 Revising Solutions

Design ideas and constructed prototypes can be evaluated through various strategies and methods (described elsewhere). The evaluation of designs and constructed (prototype) interventions generally concludes with revision recommendations. This can include suggestions on what to add, what to remove, what to alter, or even what to repeat in a design. This section briefly discusses the use of such recommendations to revise design documents or prototypes. It starts by describing different kinds of findings and then discusses considerations in reaching revision decisions.

Different kinds of evaluation and reflection findings

The stage and focus of an evaluation will set the boundaries for how far-reaching revision recommendations may go. Both design ideas (e.g. design requirements, propositions, skeleton design or detailed specifications) and constructed prototypes can be evaluated, although it is less common to conduct anything other than an informal critique of design requirements and propositions. But even if only a prototype is evaluated, the findings are quite likely to have implications for the design ideas, especially the design propositions. For example, the formative evaluation of a prototype learning environment may yield specific recommendations regarding the prototype itself, which could then be incorporated into new versions of the skeleton design and detailed design specifications.

The empirical testing of prototype features may yield findings which are more prescriptive, showing how to move forward with design. But more often, evaluation activities will reveal descriptive findings. While these may clearly warrant consideration when revising the intervention, they are not likely to specify exactly how the design should be improved. For example, observation and interview data from an evaluation of a classroom e-learning activity could provide more nuanced insight into how large or small of an innovative jump an intervention is, in comparison to current practices. Or it may reveal more about user characteristics (e.g. most of them have never seen this kind of tool before; teacher beliefs about this topic are highly varied; or children have some, but not all of the pre-requisite skills). The evaluation could also reveal participant preferences (e.g. they are happy to do this, but mostly after school), or contextual factors that were not examined in the initial phase of analysis. In fact, an evaluation may point to the need to revisit the fiend and gather new analysis data. For example, in testing a professional development program where teachers bring learner assessment data to meetings and learn how to plan lessons to meet specific needs, designers might come to question the quality of the assessments teachers bring with them. Before redesigning the program, it may be necessary to analyze currently available assessments and explore what other assessment options might be feasible.

Considering revisions

In considering how to proceed with the findings from evaluation, some design teams use established procedures for logging feedback, systematically reviewing it and creating a written trail of how it was addressed or why not. Often, it can be useful to sort problems on the basis of their complexity. Some evaluation findings will be rather straightforward and easy to use (e.g. correction of typographical errors). Some will not be easy, but the pathway to revision will be clear. Many will pose complex challenges. Complex challenges are those for which a solution is unclear or not readily available; for which numerous options for solutions exist; or for which the logical revision(s) would be beyond the scope of the project. Very often, complex challenges are prompted by tensions between differing design goals. For example, what is practical for users might make it easier to implement, but less effective; or what has been shown to be effective is not sustainable. In some cases, insufficient practicality is a barrier to even studying effectiveness. To illustrate, if an online learning environment has poor usability, it may have low effectiveness not because of the content or learning activities, but because of the inadequate human computer interface (Reeves & Carter, 2001). Revisiting design requirements and design propositions can sometimes help to weigh off options in such cases. Consulting experts (in person or through literature) may also help.

In dealing with complex re-design challenges brought into focus by evaluation, it is important to remain distanced and open-minded. It is also critical to stay in touch with the main goals to ensure that revisions reflect responsive evolution (e.g. redesign to better meet the stated goals) and not 'mission creep' (e.g. redesign changes goals without realizing it). Especially those intensively involved in the project might do well to take a break after analyzing the results and before determining revision suggestions. In some teams, the agreements are made that design authority changes hands at this point. The idea behind this is that designers can become so attached to their work, that they are unable to do what is sometimes necessary in prototyping: 'kill your darlings.' In some cases, it can be productive to concentrate (partly) on other issues, while looking to see if a solution may be found indirectly, through working on the related problems.

It is wise to plan the revision process, just as it is wise to plan the initial development. A general rule of thumb for the timing of revisions is that it pays off to tackle simple issues that take relatively little time immediately, using the 'touch it once' principle. That is, if it takes a relatively short amount of time to do, it is more efficient to do it immediately than to carry it around on the 'to do' list. It is also important to initiate changes in a timely fashion, so that those which take a long time, even if they require little monitoring, do not hold up development. Complex problems should be sorted into those that will be tackled in the re-design; those that can or will not be solved prior to the next evaluation but will be addressed; and those that will be left unaddressed. Documenting each of these is extremely important to help reconstruct events when reporting on the process. Bulleted lists or tables of issues/actions work very well; these can be sent around to the design team for review and comment. It is also important to ascertain if the changes are more superficial (e.g. constituting improved actualization of the design propositions); or more substantial (e.g. altering the underlying design propositions). Planning the revision process may also include building in time to consult literature, especially when more substantial changes seem necessary.

4. SUMMARY

4.1 Overview of the process

As described above, the process of design may feature parallel activities, but typically evolves from exploration of possible solutions to mapping of chosen ones. Thereafter, construction typically entails an iterative process of building initial prototypes and then revising them. Along the way, technologies can support the work in each step. Table 6 offers an overview of supportive software that may be helpful when tackling educational design and construction.

Table 6 Examples of supportive software for each step in design and construction

Phase		**Step**	**Supportive software examples**
Design	***Exploring solutions***	Generating ideas	Concept mapping
		Considering ideas	Spreadsheets, tables
		Checking ideas	Flow charts, diagrams
	Mapping solutions	Requirements & propositions	Reference, visual bookmarking
		Skeleton design	Sketch, draw, outline
		Detailed specifications	Multi-author, hyperlinked docs
Construct -ion	***Building solutions***	Creating initial prototypes	Varies per solution, e.g. word processing, presentation, video-editing, html editing, social networking
	Revising solutions	Revising prototypes	

4.2 Outputs of the process: Products describing and embodying design ideas

This phase consists of two main activities: designing and constructing. Similarly, two main kinds of results emerge: products describing and embodying design ideas, respectively. Products resulting from design activities describe potential solutions (generating ideas; considering ideas; and checking ideas) as well as chosen ones (refining design requirements and design propositions; establishing a skeleton design; and setting detailed design specifications). Design requirements delineate functions, criteria, opportunities, constraints or conditions to be incorporated into the solution. Design propositions are based largely on literature, and constitute the mechanisms that will enable designs to work. The skeleton design and the design specifications bring the solution closer to reality; and when design requirements and especially propositions are explicated, contributions can be critiqued and shared with others. Products resulting from construction activities embody the design ideas. These are often successive prototypes of the desired intervention.

4.3 After design and construction

Working to develop the products of this phase, which either describe or embody design ideas, may give rise to the conclusion that additional analysis is needed before redesign and/or testing should take place. For example, in constructing an intervention that includes use of social media, designers may conclude that they require additional understanding about how and when the target group currently uses specific social media tools and functions. But more frequently, some form of evaluation and reflection takes place next. Even early products describing or embodying design idea can be evaluated. Thereafter, evaluation findings can lead to new insights, design considerations, and/or ideas for (re)design.

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