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Additional Information:

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The Presentation of Systems Thinking in Support Materials for Secondary Design and Technology pupils: A review

Torben Steeg, University of Manchester, UK

Abstract

Systems ideas as a tool for supporting pupils’ thinking about a wide range of situations in design and technology (D&T) are now well established in UK curricula, syllabuses and texts. There is, however, circumstantial evidence from examinations, books and observation of work in lessons that the understandings and uses of the system diagrams common in school D&T are diverse and, often, confused, both with each other and other types of system diagram. Such confusion is unhelpful to both teachers and pupils. This paper describes, firstly, an instrument for analysing the system diagrams presented to pupils in school texts and, secondly, an analysis of a range of texts using this instrument. The analysis highlights a wide range of problems in the portrayal of both flowcharts and system diagrams in texts for school pupils. In addition, the survey indicates that problems with the portrayal of system diagrams are more widespread and deep seated than those relating to flowcharts. It is suggested that the common practice of authors of school texts referring to existing texts is a likely reason for the perpetuation of this problem. The paper concludes with some suggestions for improving the quality of information about systems thinking provided for teachers and pupils.

Keywords

systems, control, flow charts, diagrams, text books, electronics

Introduction

Systems ideas as a tool for supporting pupils’ thinking about a wide range of situations in design and technology (D&T) are now well established in UK curricula, syllabuses and texts. In particular, they have proved to be powerful in helping pupils from Key Stage 2 onwards design and make in the area of electronics by masking a great deal of technical complexity (Bevis, 1983; Martin, 1990, 1993; Steeg, 1995). For this reason, systems thinking is an important strand of the National Curriculum for D&T (DFES, 1999) and the Marconi ECT (Electronics and Communications Technology) initiative (DATA, 2002). Systems-based approaches are commonly used in D&T to support high level approaches to complex situations when pupils are designing and making control systems, to help pupils analyse and describe the designs of others, for example, in product analysis activities, and as descriptive tools when pupils need to understand the operation of complex entities, such as a manufacturing system or some element of an ecosystem. It is noteworthy that systems thinking is also used in science education (especially the biological sciences), in ICT to support the teaching of programming and in the humanities as an explanatory tool when dealing with complex entities.

At the heart of systems thinking are system diagrams used to illustrate the key elements of a system and the relationships between these elements. The author (2000) has summarised the development of systems thinking over the last hundred years and, in particular, noted the wide range of diagrammatic tools that have been developed within the various contexts for system thinking. In secondary D&T education, just two types of system diagram are in common use: block diagrams, derived from control theory and flow diagrams, often based on those used in software development. There is, however, circumstantial evidence from examinations, books and observation of work in lessons that the understandings and uses of both kinds of system diagram are diverse and, often, confused both with each other and other types of system diagram.

This paper describes, firstly, an instrument for analysing the system diagrams presented to pupils in school texts and, secondly, an analysis of a range of texts using this instrument.
The range of system diagrams

System diagrams are central to systems thinking because of the way that they allow the key elements of interest in a system to be abstracted and revealed. For this abstraction and revelation to be successful, the diagrammatic elements need to be well defined. In essence, a system diagram consists of two elements; two-dimensional shapes (which this paper will refer to as 'blocks' irrespective of their actual shape) and connecting lines ('lines') whose paths may be straight or curved and which may include arrowed ends. The differences between the different kinds of system diagram lie in the meanings they attach to the lines and the blocks. Table 1 lists some of the meanings that have been attached to both lines and blocks in various branches of the systems literature (see Steeg (2000) for an overview of this literature).

This analysis of lines and blocks indicates that 56 (8 by 7) different system diagram types may be possible by combining pairs of the various block and line elements (though some combinations may make little sense); for example, a type '4D' diagram could be used to describe the linking of nodes in a network (for example, the map of the London Underground system, or a computer network), whereas a type '8A' diagram might describe the transactions in a financial system.

What should be clear from this description of system diagram elements is that simple provision of a diagram to explain or illustrate a system will not, of itself, provide a great deal of illumination; the diagram needs to be accompanied by a lucid description of the meaning attached to the diagrammatic elements. Without this description, the 'reader' of the diagram is left to guess what the elements represent, based on previous experience with diagrams and any implicit or contextual cues. In school D&T education two types of diagram are common; flowcharts and 'block' or 'system' diagrams. Flowcharts are used to define sequences of instructions; in D&T this is generally either in the context of computer control programming or to describe a pupil's (or an industrial) manufacturing sequence. A flowchart is made up of various blocks that show a set of procedures that need to be carried out and arrowed lines that show the sequence of execution; thus a flowchart is a type 1C diagram (Figure 1).

Table 1: The uses of lines and blocks in system diagrams.

<table>
<thead>
<tr>
<th>Lines can represent</th>
<th>Blocks can represent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Order; usually arrowed, the lines indicate in which order blocks should be visited.</td>
<td>A An entity; for example a person, a role, a component or a machine.</td>
</tr>
<tr>
<td>2 A value; this might be a numerical value or a number representing a physical entity such as a signal strength or amount of some material.</td>
<td>B A function; this may be purely mathematical or describe some other kind of operation such as a change in signal type.</td>
</tr>
<tr>
<td>3 A relationship; for example indicating hierarchy in an organisation, conceptual links or influence.</td>
<td>C Instructions; for example in a computer programme or a procedure for carrying out an operation.</td>
</tr>
<tr>
<td>4 A physical link; for example between nodes in a network.</td>
<td>D A point in space; such as a node in a network.</td>
</tr>
<tr>
<td>5 Movement; of material goods or information.</td>
<td>E A value; this might be a numerical value or a number representing a physical entity such as a signal strength or amount of some material.</td>
</tr>
<tr>
<td>6 Changes of state; representing what triggers the movement between states and how it is achieved.</td>
<td>F A state; i.e. the state or condition of a system.</td>
</tr>
<tr>
<td>7 An entity; for example a person, a role, a component or a machine, an activity.</td>
<td>G A system activity; representing the purposes of the system.</td>
</tr>
<tr>
<td>8 Transactions; for example between individuals or groups in an organisation.</td>
<td></td>
</tr>
</tbody>
</table>
The second type of diagram frequently met in D&T is often simply called a 'system diagram', in defiance of the broad range of such diagrams that exist; this convention is followed in the rest of this paper. This uses arrowed lines to show signals that transfer information between blocks whose purpose is to operate in some way on these signals. These are type 2B diagrams and are commonly used to describe the functional operation (as opposed to the physical construction) of a range of control systems including electronic and mechanical systems (Figure 2, derived from Bertalanffy (1972: 34)).

Figure 2 includes a feedback signal that allows the system to monitor its own response; feedback (where the signal provided by a system is returned to it as an input) is an important element of many control systems and a concept easily described by this kind of system diagram. It is a National Curriculum requirement that Key Stage 3 pupils are taught about feedback (DfEE, 1999).

Interestingly for this analysis, a type 2B diagram describing the function of an electronic system may in some cases also be interpreted as a type 4A diagram in which lines represent signal connections (wires or ‘buses’ of wires) and the blocks represent functional areas of the circuit that map directly to components. In other words the step from the abstraction of some kinds of type 2B functional diagram to a circuit diagram may be quite small.

Note that in both cases (of flowcharts and ‘system’ diagrams) the blocks represent, broadly, operations even though the types of operations represented are different; flowchart blocks being instructions to do something and ‘system’ blocks being operations on signals. The lines, however, represent very different things, in the first case defining the sequence of operations and in the second carrying signals between operations. If these diagrammatic elements are not well defined, it would not be surprising to find some confusion in pupils’ (and teachers’) minds about the appropriate use and interpretation of these diagrams.

The next section of this paper submits ‘system’ diagrams found in school D&T texts, to a scrutiny based on the analysis of diagrams summarised in Table 1. In particular the following questions are asked:

- Are the diagrammatic elements clearly described in the accompanying text?
- Is feedback well defined?
- Does the diagram follow the usual conventions for its type? The evidence for the conclusions drawn here is based either on the diagram description provided or, in the absence of this description, on scrutiny of the diagram in its context.

System diagrams in school texts

The results reported here are based on a survey of 25 current school texts covering, between them, the 11-18 age range of D&T and focused on the teaching of either electronics/systems and control or resistant materials/graphics. Some of the ‘texts’ consist of more than one linked book or folder of materials but are considered as a single text for the purposes of this analysis.

The description of diagrammatic elements

Of the books surveyed, four make no mention or use of flowcharts. Of the remaining 21, 13 contain a clear description of the purpose of a flowchart and explicitly define a set of block elements and provide examples of use (Table 2). In all these cases the definitions of blocks given are identifiably related to the standard flowchart elements for either programming or for production planning. The purpose of line elements is implicit in all but two texts.

Just two books make no mention at all of systems diagrams or systems thinking. Of the remaining 23, seven provide a coherent explanation of a systems diagram (Table 2), the other 16, despite making at least some reference to systems thinking and the associated diagrams, provide no clear and accurate description of what a system diagram is trying to depict.

<table>
<thead>
<tr>
<th>Flowcharts</th>
<th>No mention</th>
<th>No correct description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 (16%)</td>
<td>8 (32%)</td>
<td>13 (52%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Diagrams</th>
<th>No mention</th>
<th>No correct description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 (8%)</td>
<td>16 (64%)</td>
<td>7 (28%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feedback</th>
<th>No mention</th>
<th>No correct description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 (28%)</td>
<td>5 (20%)</td>
<td>13 (52%)</td>
</tr>
</tbody>
</table>

Table 2: The description of diagram elements in school texts (n=25).
The depiction of feedback

Seven of the texts surveyed make no mention at all of feedback. Of the 18 texts that do at least mention feedback, five provide no clear or correct description of feedback (Table 2). Of the 13 that do provide a correct description of feedback, four do so correctly, but only implicitly, through a system diagram of a feedback system. The remaining nine define feedback in both words and a diagram.

The diagrammatic conventions used for flowcharts:

A difficulty for children learning how to use flowcharts in D&T may be the wide range of purposes that these diagrams serve. In a typical D&T text there may be three identifiable separate uses:

1. To illustrate a wide range of sequential activities (such as planning a risk assessment, undertaking a survey or a system for recycling). These are generally drawn using either plain rectangular boxes or (in texts for younger pupils) graphic elements to show the steps in the sequence.

2. To define a production sequence. Some texts also use plain rectangular boxes for this purpose (often drawn to look exactly like a system diagram, others use programming style flowcharts (as in Figure 1) and six use a formal production flowchart convention (see Figure 3).

3. To define a (usually control) programming sequence. The diagrammatic form used is always similar to that shown in Figure 1.

However, these differences in purpose and form, of what is essentially the same diagram type (type 1C in the analysis above), are not drawn out explicitly in any of the texts examined. Also implicit (rather than explicit) in almost all texts is the use of the lines (usually arrowed) to define sequential order.

Over a third of texts using flowcharts either do not provide a clear description of their elements, or fail to even attempt to describe them to pupils (Table 2).

Within those that make flawed attempts, the errors presented include:

- Using multiple diagrammatic forms with no explanation or apparent purpose; one text has four ‘styles’ of flowchart in as many pages.
- The suggestion that flowcharts and system diagrams are similar or interchangeable or that one is a subset of the other.
- Completely hybrid system/flow diagrams (e.g. where, without differentiation, some arrows clearly define the flow of a sequence and others are labelled as signals).
- Providing a description of the elements and then not using the defined elements in the examples provided.
- The provision of exemplar flowcharts that are clearly flawed in their structure (e.g. having a flow line split without a decision box to define the flow route).
- Providing flowcharts that have the same diagrammatic appearance as a system diagram alongside actual system diagrams, with no attempt to differentiate between them.
- The suggestion that the flowchart shows a flow of material/energy/people/information etc., i.e. that the arrows are type 2 or 5 as opposed to type 1 (Table 1).
- The suggestion that the blocks represent people (as opposed to activities), i.e. that the blocks are type A as opposed to type C (Table 1).
- Describing a flow loop (for example, a decision box monitoring the state of an input signal) as a feedback loop. (The loop of flow monitoring a signal in a flow diagram can never be properly described as a feedback loop, even if the signal being monitored has indeed been fed back from the system’s outputs. However this does seem to be a common misconception, one repeated in the Key Stage 3 National Strategy’s materials for ICT (DfES, 2003: 25).)
- The description of an endless cycle of flow (for example, to control a set of traffic lights) as a feedback loop.

The diagrammatic conventions used for system diagrams:

In those texts that provide a clear description of a system diagram the conventions used are standard (see Figure 2). However, even these texts are not free
of errors in the ways that they use these diagrams either to help explain control systems or in product evaluation. These errors include:

- confusing input and output signals with, respectively, input and output blocks
- omitting the input and output signal arrows
- the presentation of convoluted diagrams where the signal flow has not been thought through (for example, in a product analysis trying to convey both electronic and mechanical control on the same diagram, including power supplies inappropriately)
- the implication that flowcharts and system diagrams are similar or interchangeable or that one is a subset of the other.

More than two thirds of texts using systems diagrams either did not provide a clear description of their elements or failed to even attempt to describe them to pupils (Table 2). In these texts the errors presented include those noted above, plus:

- the undifferentiated and undefined use of system components rather than a description of system function.
- A great deal of inconsistency, in a single text, in the way system diagrams are used.

Some speculations on the findings

The fact that the attempt to clearly define the diagrammatic conventions for flowcharts is more common in D&T texts than the attempt to define those for system diagrams is interesting. It suggests that the authors are either more confident in their handling of the conventions of this form of diagram or that the source materials for flowcharts that they turn to when writing are more accessible. A combination of both explanations is likely. A third possibility is that authors see system diagrams as having less importance than flowcharts in pupils’ work in D&T; the high profile of systems ideas in the National Curriculum for D&T makes this unlikely.

The first two possibilities are supported by the fact that of the seven surveyed texts that provide a clear and correct definition of a system diagram, just four go on to make significant use of these diagrams to support pupils in gaining a systems level understanding of technical areas such as mechanical control and electronic/computer control. It is hard to avoid the conclusion that the authors of the other three texts (and those of the 16 texts without a proper definition of a systems diagram) either couldn’t see a purpose for the diagrams in their text or were not themselves able to use the diagrams for this purpose.

Many authors appear to be including token systems diagrams (because their understanding is required by the National Curriculum) while having little understanding of either their correct form or potential usefulness. If this is the case, why should it be so?

Authors of school texts will, commonly, turn to existing texts for inspiration, to confirm their understanding of appropriate level and coverage and, crucially, to ‘bone up’ on material they feel insecure about. But the less secure authors are in their understanding of a content area, the lower will be their ability to be critical when reading in that area – and the more likely they will be to perpetuate any errors in the source in their own writing.

When writing about flowcharts, authors of D&T texts have two easily accessible sources to help them; school texts based in both ICT and ‘control technology’ and modern control software that is flowchart based (e.g. Data Harvest, 1998; Economatics, 2000). The books from both areas have traditionally provided clear descriptions of the flowchart symbols alongside both
programming and ‘real life’ examples to help pupils understand their use. Use of the ubiquitous flowchart-based control software helps embed both the purpose and formalism of flowcharts in the user.

In contrast, authors writing about system diagrams are hard pressed to find even a slightly recent book that describes their uses and formalisms clearly. And the use of systems-based control software (e.g. Longman Logotron, 2000) is much less widespread in schools, so one avenue to practical experience with systems diagrams may not be available. It would not be surprising if some authors drew intuitively on their understandings of flowcharts to help them interpret and then describe system diagrams; this kind of confusion is certainly common in the surveyed texts.

To see another route to how the description of system diagrams may have become confused, look again at Figure 2. When system diagrams and their associated ideas were first being appropriated for use in schools, the authors ‘translating’ the ideas from academic texts in systems and control engineering looked, rightly, to simplify the language. The result of this can be seen in Figure 4.

Here the language is much more accessible for both those teachers who are not experts in control engineering and pupils. However, a seed for confusion has been sown by calling both the input block (a function) and the input arrow (a signal) ‘Input’ – and doing the same on the ‘Output’ side. Without the guidance of the technical terminology in Figure 2, it is a small step to conflate the meanings of the two ‘inputs’ and ‘outputs’ and thus the meaning of the blocks and arrows; another common mistake in the texts surveyed. This likelihood of conflation could perhaps be reduced by using the labels ‘Input signal’, ‘Output signal’, ‘Input block’ and ‘Output block’

Once the conflation of signals and functions has taken place it is not a big step to losing the information that Figure 2 is an archetypal diagram; the three blocks represent three types of block in an electronic system; those that take outside signals into the system and create electronic signals, those that process electronic signals (and create electronic signals) and those that take electronic signals and provide signals to the world outside the system. Instead Figure 4 can become, incorrectly, seen as a ‘rule’ that insists that all systems have these three blocks. The result of this is seen in descriptions of simple mechanical systems being contorted to ensure that all three blocks have a meaningful label and in complex systems being squeezed to fit into the three blocks provided.

Conclusions
This survey has highlighted a wide range of problems in the portrayal of both flowcharts and system diagrams in texts for school pupils. In addition, the survey indicates that problems with the portrayal of system diagrams are more widespread and deep seated than those relating to flowcharts. It has also suggested that the common practice of authors of school texts referring back to existing texts may be one reason for the perpetuation of this problem.

If the authors of the surveyed texts are having difficulties in accurately describing the formalisms and uses of these diagrams, it is reasonable to hypothesise that the teachers and pupils who use these books to support learning will have difficulties in making use of the diagrams. A pilot study of pupils’ understandings of system diagrams by the author indicates that this may well be the case, revealing very similar confusions to the ones to be found in textbooks (this will be fully reported in a later paper).

The D&T community, and, perhaps, in particular those members within it who have expertise in the areas of systems and control, needs to give thought to ways of breaking the cycle of propagation of inaccurate information in this area. Suggestions for doing this include:

- Encouraging the use of systems-based control software so that teachers and pupils have experience of practical work with systems diagrams and their associated ideas.
- Working with publishers to ensure that the information on systems in their books is both accurate and provides practical support to help
pupils use systems ideas to improve their designing and product analysis in technical areas; both aspects of practice that continue to draw criticism from OFSTED (2002). The Marconi ECT website (DATA, 2002) provides a good model for this.

• Working with the examining boards to ensure that their support materials and linked texts contain accurate information, that all their examiners have a sound understanding of systems ideas and that the examining of systems thinking is linked clearly to the development of D&T capability.

• Working with Government agencies and initiatives to ensure that all their publications, such as those supporting the Key Stage 3 strategy, contain accurate information. This will mean communicating clearly with colleagues working in information and communications technology (ICT) to ensure that a common approach is made between the two subjects. There may be a role here too for the Key Stage 3 Strategy D&T pilot (materials for this are currently being drafted for piloting in 10 LEAs in the academic year 2003–2004).

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