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Making Digital Systems Understandable through Primary STEAM Design

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Abstract: Primary pupils encounter digital devices long before they can explain how an input becomes an output. This conceptual article develops a STEAM lesson architecture that makes simple digital systems available for prediction, modelling and revision. Selected engineering-design standards and scholarship on integrated education inform a design analysis organised around representational transparency. The resulting architecture links a human need, a physical model, an explicit processing rule and a digital or simulated response. A worked classroom design involving an accessible classroom sign illustrates the relationship between scientific observation, technology, engineering constraints, visual communication and mathematical reasoning. The analysis also identifies evidence that can distinguish an attractive artefact from an explained system. No classroom trial or measured improvement is reported. The contribution is an instructional design proposal whose feasibility, accessibility and learning value require empirical investigation. The architecture is intended to support informed local adaptation rather than prescribe a national curriculum.

Keywords: primary education; STEAM integration; digital systems; input and output; model-based learning; engineering design.

1 Introduction

A pupil may confidently operate a device while understanding little about the conditions that make it respond. Pressing a button and observing a change are not equivalent to explaining a system. Primary education therefore needs activities in which learners can predict an output, inspect the rule producing it and identify why an expectation was not met. This article concerns that explanatory dimension of learning about the digital world.

STEAM is used here to denote deliberately connected work in science, technology, engineering, the arts and mathematics. The inclusion of a drawing or a device does not itself demonstrate meaningful integration. Perignat and Katz-Buonincontro's review describes substantial variation in how STEAM is defined and studied [1]. The present proposal consequently states what each disciplinary contribution does within one shared design problem.

The research question is how a primary STEAM activity can make the relationship between input, processing and output understandable without requiring complex hardware. The intended contribution is a lesson architecture supported by a worked design example and evidence criteria. It is not an account of an intervention already implemented, and it does not claim that STEAM is more effective than other approaches.

The target setting is approximately upper primary, subject to local curriculum and readiness. Pupils need opportunities to describe a condition, follow a short instruction and compare a prediction with an observation. These prerequisites are functional rather than fixed age norms. The

design can begin with teacher-operated materials and later incorporate pupil-controlled software when appropriate.

2 Materials and methods

This is a conceptual design study based on purposively selected publications. The source base comprises the STEAM review [1], the National Academies report on STEM integration [2], the grades 3–5 engineering-design material within the Next Generation Science Standards [3], and the named DigComp 2.2 publication [4]. The sources were selected for disciplinary integration, design constraints and the language of digital competence. They do not constitute a systematic review or a sample of school performance.

The analysis moves from a curricular intention to a proposed activity and then to an evidence claim. Three design questions guide that process: can the pupil inspect the relevant rule, can one condition be changed without changing everything else, and can the pupil explain the resulting difference? A lesson is considered representationally transparent when its model makes those relationships discussable. This is an author-generated design criterion, not a validated scale.

The NGSS material connects simple design problems with criteria and constraints [3]. The present architecture adapts that principle to a classroom communication problem. The disciplinary mapping and lesson sequence below are proposed applications; they are not statements that the cited standards prescribe this particular lesson. No participants were recruited, no observations were collected and no statistical results are available.

3 Results

3.1 A shared design problem

The proposed problem is to create a classroom sign that communicates whether a quiet working area is available. The sign must respond to a specified input and remain understandable to users who cannot rely on colour alone. The problem brings a human purpose into the design before pupils select software or decorative materials. It also provides a criterion that can be checked: another pupil should interpret the output correctly.

Initially, an input card indicates either available or occupied. A pupil acting as the processor follows a written rule and places the corresponding sign. The teacher then introduces an invalid or missing input. Pupils decide whether the rule defines what should happen. The activity makes visible that a system needs instructions for the cases it is expected to handle; an attractive output cannot repair an unspecified condition.

Table 1. Disciplinary functions within the proposed sign project

Area	Function in the shared problem	Evidence to retain
Science	Observe how a visible signal is perceived under different conditions	A comparison of two viewing conditions
Technology	Represent an input and produce an output through a rule	A labelled input–rule–output account
Engineering	Meet user needs within material and time constraints	A revision linked to a criterion

Arts	Use shape, layout and symbols to communicate meaning	An explanation of a visual choice
Mathematics	Classify states and compare counts or timings	A consistent table of cases

The mapping is not a requirement to allocate equal time to every area. It tests whether each included area has a meaningful role. If an activity contains no scientific question, a teacher should narrow its integration claim rather than attach a science label. Disciplinary honesty allows a short lesson to remain focused while situating it within a longer STEAM sequence.

3.2 From physical representation to a digital response

The instructional sequence begins with a prediction: pupils state what the sign should show for a given input. They construct a physical model, write the rule, exchange models and test an unannounced case. They then revise either the rule or its representation. A teacher-controlled digital version can subsequently demonstrate the same relation through a simple conditional action.

A physical model and a digital implementation are related but not identical. In a human simulation, a pupil may silently interpret an ambiguous instruction. A digital system will follow the implemented operations rather than infer the intended meaning in the same way. Discussion should therefore ask which human decisions have been made explicit in the program and which remain outside the model.

Table 2. Proposed sequence and explanatory questions

Phase	Pupil action	Teacher question
Specify	State who needs the sign and why	What must another user understand?
Predict	Write the expected output for one case	Which input are you assuming?
Model	Represent the processing rule	Could someone else follow this rule?
Test	Compare expected and observed outputs	Where does the mismatch begin?
Revise	Change a justified feature	What evidence supports the change?
Transfer	Consider a related signalling problem	Which rule still works and which changes?

The sequence does not require sensors, robotics equipment or online accounts. Such equipment can be added only if it contributes to the intended explanation. A sensor reading introduces measurement conditions and possible uncertainty; it should not be described as automatically revealing the true state of a social situation. A button selected by a human and a sensor detecting a physical condition are different kinds of input.

3.3 Evidence of learning

The proposed evidence set includes a labelled model, a prediction for a new case and a brief individual explanation. These products are examined separately. A functioning sign demonstrates that the current arrangement produces a response, but it does not establish that every group member understands the rule. Each pupil should therefore explain one input change and its consequence.

A useful contrast is between "it changes because I pressed it" and "the input changed, and the rule selects a different symbol." The second statement makes a relationship explicit, but it still needs testing with another case. These are invented response examples used to clarify an assessment decision; they are not participant data. Teachers should also record whether the explanation depended on a substantive prompt.

3.4 A counterexample task

The teacher changes the visual appearance of the sign while keeping its rule unchanged, then changes the rule while keeping the appearance unchanged. Pupils identify which change affects the system's behaviour and which affects communication. The purpose is to separate interface features from processing decisions. Both can matter to users, but they answer different questions.

An extension asks whether the sign stores any information after the input is removed. This introduces the idea that not every system remembers a previous state. Pupils are not required to learn formal memory architecture. They simply compare a momentary response with a persistent record and state what their model does. Such boundaries help prevent a simple classroom analogy from becoming an inaccurate general explanation of computers.

4 Discussion

The architecture connects disciplinary contributions through a common explanatory demand. The arts contribution concerns how meaning is communicated, while engineering concerns whether a solution meets a user requirement. These roles interact: an understandable symbol can help satisfy a criterion, and a user test can reveal a need to redesign the symbol. Neither role is reduced to decorating a technical product.

The National Academies report addresses the opportunities and research questions associated with STEM integration [2]. The implication developed here is that integration should be described precisely enough to investigate. Future observation could distinguish time spent constructing, explaining and revising. Without that distinction, a positive reaction to materials might be mistaken for understanding of digital systems.

DigComp 2.2 supplies a vocabulary that includes content creation and problem solving [4]. The present project samples a narrow part of that broad territory. Explaining a conditional classroom sign does not establish overall digital literacy or safe online judgement. Reporting must remain tied to the action that the task actually makes observable.

Feasibility depends on language, time and access to manipulable representations. A pupil who cannot easily write the rule may explain it orally or arrange symbol cards, provided the target is the rule rather than writing fluency. However, an alternative response mode must preserve the relationship being assessed. Removing every demand to specify the rule would remove the intended evidence.

The proposal requires empirical testing. A classroom study could investigate whether pupils distinguish interface changes from processing changes and whether their explanations transfer to another simple system. It would need to document teacher support, prior experience and task accessibility. Comparisons between teaching approaches would require comparable learning time and assessment conditions; no such comparison has been conducted here.

5 Conclusion

Primary STEAM design can be organised around making digital relationships explainable. The proposed architecture connects a user need, a transparent rule, a testable response and a justified revision. Its contribution is a teachable route from operating a representation to reasoning about it. The worked sign project and evidence criteria remain design proposals that require classroom investigation before claims about learning gains are made.

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