EXPLANATORY PAPER

The Technological Knowledge Strand: Technological Modelling

ABSTRACT

The purpose of this explanatory paper is to define technological modelling and clarify the role and nature of functional modelling and prototyping. It presents the component descriptor, the key ideas underpinning it, and illustrative examples of these from technology. This paper also suggests possible learning experiences.

COMPONENT DESCRIPTOR

Technological modelling refers to modelling practices used to enhance technological developments and includes functional modelling and prototyping. *Functional modelling* allows for the ongoing testing of design concepts for yet-to-be-realised technological outcomes. *Prototyping* allows for the evaluation of the fitness for purpose of the technological outcome itself.

Through technological modelling, evidence is gathered to justify decision making within technological practice. Such modelling is crucial for the exploration of influences on the development of the proposed outcome, and for the informed prediction of the possible and probable consequences of the proposed outcome. Technological modelling is underpinned by both *functional and practical reasoning*. Functional reasoning focuses on “how to make it happen” and “how it is happening”. Practical reasoning focuses on “should we make it happen?” and “should it be happening?”

Decisions as a result of technological modelling may include the termination of the development in the short or long term, continuation of the development as planned, changing/refining the design concept and/or the nature of the technological outcome before proceeding, or to proceed with the prototype as planned and/or accept the prototype as fit for purpose.

KEY IDEAS

A model is a representation of reality. In technology, functional modelling is used to represent how things might be if a technological development was to continue to determine whether and how the development should proceed. Prototyping is used to evaluate the outcome itself once it is realised. Technological modelling is critical in the process of identifying the outcome’s potential and probable impact on the world, as it moves from conceptual idea through to being fully realised and implemented *in situ*. It also supports exploration of a range of influences that may impact on technological outcome, its development, and its future manufacture.

Technological modelling is a key tool for technological development across all technological domains. However, the specific knowledge and skill base underpinning the implementation of technological models and the interpretation of data gained is particular to domains.

The media used, and types of procedures undertaken in technological modelling, vary depending on the stage of development, preferences, requirements, and the capability of the technologist2. The audience from which input and targeted feedback is sought will also influence the type of media and model used. For example, at the early stage of development, functional modelling may simply involve the technologist thinking through their design ideas and/or discussing these with other technologists to test their suitability. As the development moves on, this may progress to drawings on paper or within computer programmes, then to more formal written and/or diagrammatic explanations appropriate for a wider range of audiences. Three-dimensional mock-ups, using easily

2 As discussed in CoT, contemporary technological development often involves more than one person. In the figure and discussion, therefore, “technologist” is used in an attempt to simplify the practices being described. In reality, the “technologist” may be a group of people and the make-up of this group may change as the development proceeds and different skills and knowledge are required.

manipulated material such as clay, cardboard, Styrodur foam, and CAD software, are often used to enable design ideas to be evaluated in terms of technical feasibility and social acceptability. Progressively, the materials used become more closely aligned to the actual materials that will be used in the final outcome, with the final prototype using these exclusively.

Technological modelling can be categorised into two related types – functional modelling and prototyping. The difference in type is linked to what is being modelled, the purpose of the modelling, and the stage in the development that it is taking place.

Functional modelling is often referred to by different names across different technological domains. For example, functional modelling may be referred to as test or predictive modelling in biotechnology, animatics in film making, a toile in garment making, and mock-ups or mocks in architecture and structural engineering. In all these cases, what is being modelled, or represented, is the yet-to-be realised technological outcome for the purpose of testing design concepts with regards to the physical and functional nature of the outcome required by the brief. Design concepts include design ideas for parts of an outcome as well as a complete conceptual design for the outcome as a whole.

Functional modelling, therefore, provides a tool to support informed projections into probable future impacts; allowing for the exploration and evaluation of design concepts, from a range of perspectives, from which to make justifiable decisions regarding the technical feasibility and social acceptability of any future development. These decisions need to take into account such things as known specifications, material and technique suitability, and historical and socio-cultural factors. If these are not taken into account, the likelihood of unintended negative consequences resulting from a technological outcome increases.

The earlier in the development that functional modelling occurs, the stronger the focus is on “go/no-go” decisions. If a “go” decision is made, the result may be to revise the design concept or move on to the next stage in development of the original design concept. Functional modelling should, therefore, occur extensively in the early stages of technological practice, when establishing whether the design concept being developed has worth (in its widest social sense) and when “what if” questions need to be asked and explored. Early stages of functional modelling often employ “guesstimation”, based on similar technological outcomes and developments and/or drawing from other known situations or past problems/issues.

Functional modelling provides opportunity to reduce the waste of resources that can often occur if technologists rush too quickly to the realisation phase, relying on a more “build and fix” approach to technological development. Because of this, functional modelling can be seen as a key tool for encouraging and enabling more environmentally sensitive and potentially sustainable developments. The better the functional modelling, the greater the confidence a technologist can have that the fully realised technological outcome will be fit for purpose, and will result in fewer unknown and/or undesirable impacts on the world. While it may not result in the removal of all unknown or undesirable impacts, functional modelling can work to significantly reduce these through informing decision making around risk identification and management. However, all functional models are limited due to their representational nature. That is, what is being tested is only a simulation or a part of what the actual outcome will be.

Prototyping is the modelling of the realised but yet to be implemented technological outcome. The purpose of prototyping is to evaluate the fitness for purpose of a technological outcome against the brief.

At the point of realisation, the outcome has an increased impact on the world, due to the fact it now exists in a functioning material form and can be implemented in its intended location. However, prototyping seeks to gather further evidence to inform subsequent decisions focussing on establishing it’s acceptability for implementation or the need for further development. Evaluation of its fitness for purpose is measured against the specifications established in the brief. Because the technological outcome now exists in a material form, prototyping allows for a greater level of exploration of unintended consequences/impacts on people and the physical and social environment in which it will be situated.

As with functional modelling, decisions from prototyping can result in a “no-go” decision or in a significant change, meaning a need to revise the design concept. Decisions to halt or significantly change development at this point suggest earlier work may not have been undertaken in sufficient depth. This has implications for the technologist, as the costs (such as time, labour, materials, and money) involved in developing a prototype are high, and would be unsustainable should such decisions occur regularly at this stage of the development process.

Alternatively, a decision to undertake further development may be made after prototyping, resulting in less dramatic modifications, or refinement of the outcome to enhance its performance and/or suitability. Prototyping may also result in the decision to implement as is. Prototyping thereby provides the means to evaluate a technological outcome in order that its fitness for purpose can be optimised or to provide justification for the outcome to be fully implemented as fit for purpose.

Prototyping can also be used for the purpose of testing “scale-up” opportunities, and can provide key information regarding decisions around ongoing or multi-unit production and marketing for commercial purposes.

Specific methods of prototyping are validated by different communities and this must be taken account of if the outcome’s worth is to be accepted by key stakeholders and the wider community. This is not to say new methods cannot be developed. However, any new method would need to show itself to have equal or greater benefits than previously accepted practices.

Figure 1 provides a summary of functional modelling and prototyping, as types of technological modelling within technological development.

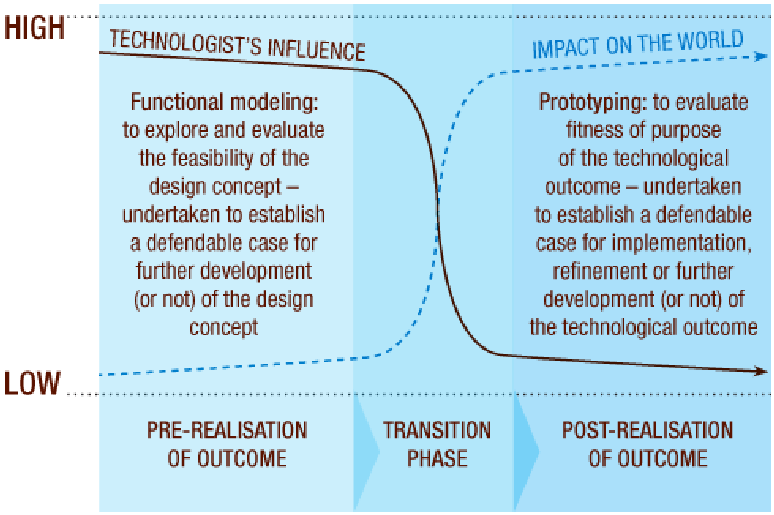

Figure 1: Technological Modelling in Technological Development

Figure 1 illustrates that a technologist’s influence on the impact their work will have in the world decreases as the development work proceeds. Initially, the technologist has high levels of control over how the design will progress (or not) and be developed. As the design becomes more developed and widely communicated, the influence of the technologist begins to *decline*. At the transition phase, where the design idea is first realised as a technological outcome in its material form, the technologist’s influence declines significantly. In contrast, the impact of the potential outcome *increases* as development proceeds towards its realisation, with a significant increase occurring at the transition phase.

The “impact on the world” includes both beneficial and harmful impacts, such as environmental, social, economic, and political benefits or costs. The transition phase should be viewed as a critical decision point in any development, for once realisation of an outcome has occurred, there is “no going back”. As a result of prototyping, however, any future development work can of course be subsequently halted, or directions changed.

Technological modelling is used to inform decisions regarding risk management through identifying and assessing possible risk factors associated with the development of a technological outcome. Assessing risk involves establishing the probability of identified risks occurring and the severity of the impact should it occur. Managing risk involves making decisions to avoid, mitigate, transfer, or retain the risk.

Technological modelling employs two types of reasoning (*functional* and *practical* reasoning) to ensure that a holistic evaluation of a technological outcome’s potential and actual “impact on the world” is made, with the evaluation reflective of a balanced normative and technical understanding of fitness for purpose. *Functional reasoning* provides a basis for exploring the technical feasibility of the design concept and the outcome. That is, "how to make it happen" in the functional modelling phase, and the reasoning behind "how it is happening" in prototyping. *Practical reasoning* provides a basis for exploring acceptability (related to such things as moral, ethical, social, political, economic, and environmental dimensions) surrounding the design concept and outcome testing. That is, the reasoning around decisions as to "should it happen?" in functional modelling and "should it be happening?" in prototyping. In this way, practical reasoning provides a framework, or rational structure, to justify what "ought" to happen – providing the crucial normative element of technology.

ILLUSTRATIVE EXAMPLES FROM TECHNOLOGY[3]

The current issue around irrigation in the South Island of New Zealand, in particular the Mackenzie Basin, provides a contemporary context to gain insight into how technologists are working to resolve issues; using both functional and practical reasoning to balance a range of stakeholder priorities and attempt to find a best-fit solution.

This example also provides insights into how a diverse group of professionals are working alongside the Government and general public to ensure all needs, including long-term environmental needs, are fully understood and justifiably prioritised for any future development decisions. For an introduction to this issue, see the May/June 2006 edition of e.nz magazine.

Exploring vehicle prototypes provides an opportunity to examine a range of historical examples, showing the way prototype cars and bikes have been used to gain crucial market feedback and ensure design flaws are identified and corrected prior to the shift into mass marketing. Examples can be found where the prototype was too far outside of acceptable norms or performance expectations to support ongoing development (for example, the early generation hybrid cars).

Other examples show how a prototype can shift people's perceptions and stimulate other technologists to cross historical boundaries (for example, the New Zealand designed Aquada). Analysis of the prototyping of vehicles can highlight the complexities associated with gaining robust end-user feedback, and the economic and personal costs associated with poor decision making leading up to the development of a prototype that fails. Henry Petroski's book, *To Engineer is Human: The role of failure in successful design,* provides descriptive accounts of the impacts of failure on technological development.

POSSIBLE LEARNING EXPERIENCES

The learning experiences suggested below have been provided to support teachers as they develop their understandings of the Technological Modelling component of the Technological Knowledge strand, and how this could be reflected in student achievement at various levels. There is no expectation that these would form the basis of any specific unit of work in technology. The learning experiences have been written in such a way as to support student learning across a range of levels. This stance reflects the majority of classrooms, where it is expected that students will demonstrate a range of levels of achievement.

Junior Primary (NE-Year 4)

Students could explore imaginative play, toys, television, and/or computer games to help them distinguish between simulated situations and reality. Teacher-guided class discussion could focus on developing an understanding of how reality is different to simulations and the implications of this. For example, when playing with a doll, children simulate the care of a baby; however, the implications of dropping the doll are quite different to dropping a baby.

Students could be introduced to the term "model" and encouraged to discuss what they think modelling is and how it might be useful in technological developments. Students are then provided with an opportunity to play with

3 These are provided for the purpose of increasing teacher background understandings of this component; however, they may also be relevant for senior students.

different modelling materials (such as LEGO, plasticine, Meccano, Connex, cardboard, concept maps, computer modelling packages, etc.) and to explore how different materials may allow greater testing of how something might work. For example, static LEGO could be compared with LEGO Technic, computer simulations could be explored with 3D models, etc. Students could then discuss their ideal playground and undertake functional modelling to decide as a group what ideas could be feasible and acceptable for a playground for their school.

Students achieving at level 1 could be expected to:

- explain that models are not the same as the real thing and describe some examples of modelling; and
- identify functional models and describe that they can help you to test design ideas.

Students achieving at level 2 could be expected to:

- describe how models can be useful to help you think about things before they happen, and how models can also make you think something is possible that isn't – or vice-versa; and
- describe the functional modelling used and identify the design ideas being tested during the class activity to make decisions about a school playground.

Senior Primary/Intermediate (Years 5-8)

Students could be provided with information about a range of models, including both functional models and prototypes, which have been used in the past development of specific technological outcomes.

Examples could be chosen from areas of interest to the students and might include such things as musical instruments, sporting equipment, cars, bikes, food products, clothing, etc. In groups, the students could identify what the purpose of each model might be and what particular characteristics of each model allowed it to fulfil its purpose. As a class, the students could discuss what things they would have to know if they were developing these models. Students identify the limitations of the model in terms of what it cannot provide information about.

Students are then encouraged to reflect on their current technological practice and undertake technological modelling of some form to guide them in the next stage of their development. As part of this, they need to clearly identify the purpose of the modelling. That is, are they testing their design idea (functional modelling), or the outcome itself (prototyping)? They also could be asked to explain why they choose the medium used, and how and from whom they would get feedback to inform their decision making. Students use their model and evaluate its effectiveness against its stated purpose.

Students achieving at level 2 could be expected to:

- describe different functional models and prototypes provided and identify the reason they were used;
- identify the design ideas being tested in particular functional models; and
- identify the specifications being used to test different prototypes.

Students achieving at level 3 could be expected to:

- identify different forms of functional models and explain why they were selected;
- identify different examples of prototyping and describe how the evidence gained allowed people to decide if the prototype needed further work or not; and
- describe the choice of modelling they undertook and how this helped and/or hindered their decision making.

Students achieving at level 4 could be expected to:

- explain a range of examples of technological modelling and discuss how each allowed the technologists to determine both what *could* and what *should* be done;
- discuss examples of functional modelling and describe the specific information they generated to help make design decisions; and
- identify the information gained from their own technological modelling (either functional modelling or prototyping) and describe how it helped them decide what to do.

Junior secondary (Years 9-10)

Students could select examples of successful (for example, Post-its, Aquada, telephones, the printing press, antibiotics, the Hamilton jet, vaccines, a past successful student outcome, etc.) and unsuccessful technological outcomes (for example, thalidomide, Chernobyl and/or Three Mile Island nuclear power plants, Cave Creek, Hindenburg airship, Titanic, Space Shuttle Columbia, Silver Bridge, early generation hybrid cars, unsafe toy and/or food products, a past failed student outcome, etc.).

They could explore the extent to which functional modelling was used during development phases, and what factors (economic, social, political, technological knowledge, etc.) influenced the developments. Particular attention should be paid to understanding key decision points and the basis upon which these decisions were made. Resources such as *Technological Accidents: Learning from Disaster* at www.econ.canterbury.ac.nz/downloads/philofit.pdf could be discussed as a basis to support students in developing an understanding of the complexities involved in managing risk in technological developments.

Examples from the students' past and current technological practice could also be brought into discussions to encourage them to identify appropriate times where functional modelling may have enhanced success. Students select a particular example of an unsuccessful technological outcome and make a case, based on a retrospective analysis and their developing understandings, for how things might have been done differently.

Students achieving at level 3 could be expected to:

- identify examples of successful and unsuccessful technological outcomes and explain the role that technological modelling played in each;
- identify the benefits and limitations of functional modelling used during technological development; and
- explain why both functional modelling and prototyping are needed to support decision making in technology.

Students achieving at level 4 could be expected to:

- identify decisions that focussed on what could happen and those that focussed on what should happen and explain how these impacted on the resulting technological outcome;
- identify information that has been gathered from functional models about the suitability of design concepts and describe how this information was used; and
- explain how prototyping has played a role in supporting the implementation of a technological outcome with both successful and unsuccessful results.

Students achieving at level 5 could be expected to:

- explain how evidence was gathered and used to the support of the development of a successful outcome and compare this with an example where the resulting technological outcome was unsuccessful;
- discuss examples of how prototyping allowed maintenance requirements to be determined; and
- outline a case for how technological modelling could lesson the chance of market failure or resulting disaster in the case of a particular technological outcome.

Senior Secondary (Years 11-13)

Students could identify a local community issue, and work alongside key stakeholders to identify their priorities and how they impact on their perceptions about what type of solution would be fit for purpose. Examples of issues could include the establishment of a marina, the restoration of a mining site, the reclamation of a wetlands area, the site of a new building sub-division, the need for flood protection, the need to stop sand dune erosion, the redesign of an accident-prone intersection, etc.

From this basis, students work to identify arguments for possible scenarios that employ both functional (what can be done) and practical (what ought to be done) reasoning, and use these scenarios to develop a series of functional models to test a range of design ideas and explore any real and/or perceived risks associated with them. Models developed could be justified in terms of purpose, medium, and the validity of the evidence they will provide in order to make decisions of "where to next?" Students could employ a range of models and gather evidence to support their decision for a recommendation of a feasible conceptual design that would address some or all of the needs/opportunities provided by the issue and mitigate identified risks.

Students achieving at level 4 could be expected to:

- explain how functional modelling can be employed to gather specific information about how a potential outcome might be perceived by key stakeholders;
- explain how technological modelling could be undertaken to test design ideas for stakeholder acceptability and technical feasibility; and
- present a design concept of a possible outcome that is explained in terms of both stakeholder acceptability and technical feasibility.

Students achieving at level 5 could be expected to:

- explain how different forms of functional modelling can be used to identify conflicts between key stakeholder priorities;
- explain the reasoning that led them to decide on a particular conceptual design as both acceptable and feasible; and
- present and justify a design concept for a technological outcome that would address the needs/desires of key stakeholders.

Students achieving at level 6 could be expected to:

- explain the difference between functional and practical reasoning and discuss how both types of reasoning informed their decision making;
- explain how the functional models used enhanced and/or limited their ability to explore and identify the risks;
- present and justify a design concept for a technological outcome that would address the needs/desires of key stakeholders and take account of informed predictions from the wider social and physical environment.

Students achieving at level 7 could be expected to:

- justify the need to gather a range of evidence through different types of functional modelling in order to make decisions about both what could and should be done in relation to a particular issue;
- employ functional modelling to identify and assess possible risks in relation to a range of design ideas developed to address a selected issue, and present an argument for how these risks could be mitigated;
- use a range of evidence to present and justify a design concept for a technological outcome that would most effectively address the needs/desires of key stakeholders and take account of predictions from the wider social and physical environment.

Students achieving at level 8 could be expected to:

- use illustrative examples from the issue explored to explain the critical role of functional modelling in making informed predications and defensible decisions regarding an outcome's suitability to address a range of competing and contestable factors inherent in the issue;
- explain and justify the use of different media and procedures in functional modelling to ascertain the risks associated with different potential outcomes based on a critical understanding of the issue, related historical development practices and past outcomes, the specific perspectives of individual stakeholders and the community as a whole, and the identified requirements of the social and physical environment in the short and long term; and
- use a range of evidence suitable for different audiences to present and justify a design concept for a technological outcome that would most effectively address the needs/desires of key stakeholders and take account of predictions from the wider social and physical environment, and outline feasible and acceptable safeguards that could be developed to mitigate identified risks.