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Framing a holistic model of reasoning in the design process in technology education

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Abstract
Understanding the reasoning in the design process is essential to comprehend design practice and promote students' learning. Followingly, to effectively support students through the design process, it is crucial to pay attention to their reasoning. Therefore, in this study, we have built a model for students' reasoning in the design process in technology education to be used as a utility in further research. Here, reasoning is viewed as the process of using premises to reach a conclusion. Drawing from philosophy of technology and philosophy of technology education, the model introduces relevant concepts that are particularly useful in technology education. The model incorporates two types of reasoning: means-end reasoning and cause-effect reasoning. Means-end reasoning involves identifying actions to achieve a desired end. While cause-effect reasoning leads to conclusions in the form of beliefs about causes, effects, consequences, and side-effects, which is important when predicting and evaluating in the design process. The model highlights the interplay between these two types of reasoning, where students would constantly move between them in the design process. The model involves a holistic view of the reasoning and the design process, rather than taking a purely instrumental approach. That the model fuse two types of reasoning, makes it applicable at any point in the design process and across different contexts in technology education. Overall, the model provides a comprehensive view of reasoning in the design process in technology education.

Keywords Technology education · Design process · Means-end reasoning · Cause-effect reasoning

Introduction

There is one significant difference between the purpose of designing and the purpose of designing in technology education. In general, designing means to transform a situation into something that is considered better (Wikberg-Nilsson et al., 2021), where the result is the final goal. In education, the purpose is for students to learn and with regards to

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design that means that they should learn about, to and from design (e.g., Seery et al., 2022). This enforces the notion that design in technology education should not be reduced to just its doing and production of technology—as that is not the purpose of education. Concurrently, designing is complex. The design process encompasses what can be seen as an infinite number of choices and considerations (e.g., Rittel, 1987). To be able to navigate within the design process and for teachers to be able to support their students, focus should be given to the student's *reasoning* within the design process. Making sense of the reasoning in design is important to understand design practice (Cramer-Petersen et al., 2019) and thus, this is important to drive students' learning. In line with this, de Vries (2016b, p. 83) emphasizes that "teaching about ethical and aesthetical aspects of technology should be aimed at helping learners to develop their own opinions in a proper way by using proper reasoning". However, reasoning is a broad concept that assumes shifting forms depending on what field claims the definition. In a broad sense, it is often meant to describe a thought process behind a conclusion, where the conclusion can be a decision, a problem solution, an action, a belief or similar (e.g., de Vries, 2016b; Evans et al., 1993; Harman, 1986). The conclusion within reasoning is preceded by premises, upon which the conclusion is drawn (Walton, 1990). This is also the point of departure for the concept of reasoning in this article.

Within curricula for technology education around the world, there is explicit focus on reasoning in some countries and implicit in others. For example, within the Swedish and the New Zealanders curricula, reasoning is explicitly mentioned as a grading criteria or achievement objective (Ministry of Education, 2018; Skolverket, 2022). Yet, what reasoning entails within the design process in technology education is vague, mainly stemming from that what reasoning in design practice is has been up for discussion for the last decades. The discussions have been carried out somewhat parallel within the fields of design research and philosophy of technology (Kroll & Koskela, 2016; Quintana-Cifuentes, 2022), where different descriptions of the reasoning in the design process have prevailed depending on the field of origin. Within the field of design research, the focus has been on the form of the reasoning, where abduction has been concluded as the main reasoning in the design process, usually referred to as *design reasoning*. Withing the field of philosophy of technology the fundamental reasoning within the design process has been identified as means-end reasoning (Kroes, 2009). This stems from the notion that the design process involves going from a need or desire to a finished design, which involves finding means to a final end. With its grounds in philosophy of technology and engineering (e.g., Hughes, 2009) this means-end reasoning is often referred to as *technological reasoning* (e.g., Alamäki, 2000; Dusek, 2006).

The aim of this study is to provide a theoretical framework for reasoning in the design process in technology education through a model. The purpose has not been to provide a completely normative- or descriptive model. Thus, the model is not a claim to reflect how students *ought* to reason and it does not claim to mirror how students *are* reasoning. However, through the lens of philosophy of technology and philosophy of technology education, the model contributes with concepts relevant to reasoning and that are especially applicable in technology education. Weber et al. (2014) urged for that appropriate theoretical frameworks would be used in research to generate empirical results of human reasoning. Hence, the intention is that this model can be useful as a theoretical framework, a common ground, for studies and discussions about and within research of technology education.

The design process, reasoning and technology education

In a wide definition the design process can be seen as consecutive actions made to reach a final goal of a mission (Wikberg-Nilsson, 2021). The available definitions of the process are numerous and descriptions of what the design process entails varies. Drawing from the theory of the dual nature of artefacts the design process can be seen as the process where the designer realizes a desired function as an artificial object (Kroes, 2012). Nevertheless, the design process is most often illustrated as consecutive steps. The design steps in technology education usually follow the symmetry: problem analysis, generating solutions, detailed design and lastly, prototyping, while in for example the engineering design process, the process would continue with manufacturing and production (Norström, 2016). The process is most often described as starting with a problem (e.g., Citrohn et al., 2022). Although Norman (2013) emphasises that the design process does not start there. It starts with understanding "what the real issues are" (Norman, p. 218).

The reasoning within this process have been investigated to a large extent within for example design research. In general, this research has had its focus on investigating designers' reasoning, where e.g., Cramer-Petersen et al. (2019) could distinguish an abductive-deductive prevailing pattern among participating designers. In technology education however, reasoning within the design process has not been investigated to any great extent. Nonetheless, Daugherty and Mentzer (2008) synthesized research made on analogical reasoning and design. Analogical reasoning is a form of inductive reasoning which entails resembling one item to another. Their results were that expert designers use analogies when designing, but they concluded that further research should be made to investigate its implications for technology education. Furthermore, there are empirical studies that have explicitly investigated reasoning in technology education while not connected to the design process explicitly. Buckley et al. (2018) identified inductive reasoning as significant to fluid intelligence, arguing that thinking processes such as inductive reasoning should be of more focus in technology education. Thorsteinsson and Olafsson (2016) and Autio and Soobik (2017) have done identical studies investigating the level of students' reasoning in technology education in Finnish, Estonian and Icelandic schools. They let students answer a multiple-choice questionnaire and measured the students' reasoning based on the number of right answers. They applied a general definition of reasoning yet defining it as technological reasoning and concluded that the level of the students' reasoning ability was fairly low. It can however be questioned whether they measured the students' technological reasoning or the level of correct answers. This further strengthens the need for a conceptual model of reasoning in technology education.

Design reasoning as abductive reasoning

The different definitions of what characterizes design reasoning originate from the work of Charles Sanders Peirce (e.g., Dorst, 2011; Roozenburg, 1993) and his identification of a third form of reasoning, *abduction*. This third reasoning type differs from deduction and induction. In deduction, the conclusion is drawn from general knowledge and the conclusion is true as long as the premises are true. While in induction, a general conclusion can be drawn from observations. Abduction on the other hand, leads to a conclusion about the particular that is probable. Unlike the conclusion in deduction, the

Table 1 Examples of deduction, induction, and abduction

	Deduction	Induction	Abduction
Premise	A diesel engine needs diesel to work	Every diesel engine I have seen needed diesel to work	A diesel engine needs diesel to work
Premise	This diesel engine works	I have seen many diesel engines	This diesel engine has diesel
Conclusion	This diesel engine has diesel	All diesel engines needs diesel to work	This diesel engine works

conclusion in abduction is not necessarily true even though the premises are true, (see Table 1). This is why Harman (1965) named the theory of abduction as *Inference to the best explanation*, meaning that the conclusion in an abduction is what should be most likely but not necessarily true.

In design research abduction has many times been deemed as the only form of reasoning that can produce new ideas (e.g., Kolko, 2010). March (1976) suggested the PDI-model (production, deduction, and induction) as an iterative process to describe the reasoning in design. Within this model, the productive reasoning was innovative abduction. Roozenburg (1993) later drew on the ideas of March and described what he called *innoduction*, innovative abduction. He distinguished this form of reasoning from Harman's (1965) *explanatory abduction* and inference to the best explanation, which he claimed were centralized to trouble shooting in the design process.

What characterize Roozenburg's (1993) description of innoduction (see Table 2) is the notion that within this reasoning the premise of a rule, $p \rightarrow q$, are in fact part of the conclusion as well. This means that this rule remains hypothetical within the reasoning. Within the case of deduction in Table 1 the rule "A diesel engine needs diesel to work" can be deemed as general knowledge. But within innoduction, such a relationship would be part of the conclusion. Roozenburg highlighted that innoduction would be the principal reasoning when generating a principal solution in design. But the analysis of the reasoning throughout the rest of the design process remained unaccounted for by Roozenburg.

In his influential work "The core of 'design thinking' and its application", Dorst (2011) describes two types of reasoning as central in the design process, abduction-1 and abduction-2. Here, abduction-1 is described in much the same way as Roozenburg's explanatory abduction or Harman's (1965) "inference to the best explanation". While abduction-2 is comparable to Roozenburg's innoduction (see Table 2). What is seminal in Dorst's work, is the notion of describing this design reasoning as one single inference through the whole design process. This can be viewed as limiting as the reasoning in the design process is not captured in one inference. It would seem as if drawing one conclusion will automatically lead to the next, and the next, and so forth. Designing does not consist of once concluding what function and form will fulfill the desire. Thus, the design process does not encompass one decision, but indescribably many.

To not reduce the design process to one single inference, Kroll and Koskela (2016) described design reasoning as a *double innovative abduction*. They draw from Roozenburg's (1993) innoduction but divide the inference into two steps. In the first step, the concept of the design is concluded. Kroll and Koskela (p. 130) define the meaning of the design's concept as "the mode of action + the way of use", meaning how the design will work combined with how it will be used. In the second step of their double innovative abduction, the form of the design is the conclusion, while the concept is given.

The notion of design reasoning as different forms of abduction is still debated. There are what seems to be two themes within this debate, design reasoning described on a macro-level and on a micro-level (e.g., Dixon & French, 2020). Here, the prefixes macro and micro refer to at what level in the design process the reasoning were defined. At a macro-level the reasoning in the design process is viewed as a single inference, while at micro-level the reasoning is explored at specific stages in the design process. Dorst (2011) and Kroll and Koskela (2016) would seem to describe design reasoning on a macro-level. Roozenburg (1993) on the other hand seem to be in the in-between, as he upholds that the innoduction would be central when designing the principal solution.

Table 2 Design reasoning as described by Roozenburg (1993), Dorst (2011) and Kroll and Koskela (2016)

Roozenburg (1993)		Dorst (2011)		Kroll and Koskela (2016)	
Innoduction		Abduction-2		Double innovative abduction	
					Step 1
q	q is a given purpose of the design	q	q is a given desired value	q	Given: function
p→q	a rule to be inferred first IF p THEN q	p→q	IF how THEN value	p→q	First conclusion: IF concept THEN function
p	p is the conclusion, the cause, that immediately follows	p	How	p	Second conclusion: concept
					Step 2
				q	Given: concept
				p→q	First conclusion: IF Form THEN Concept
				p	Second conclusion: form

Technological reasoning as means-end reasoning

Within philosophy of technology, *means-end reasoning* is many times regarded as the essential type of reasoning in the design process. Hence, it is often referred to as technological reasoning. This reasoning is one thing that contrasts technology from science, where scientific reasoning is often regarded as the essential reasoning type in the scientific inquiry. This reasoning is different from means-end reasoning. Means-end reasoning is often referred to as a form of reasoning which results in actions (de Vries, 2012). The reasoning starts with the desire of an end and through the reasoning, means to attain the end is identified. Hence, contrary to what the name suggests, the flow of means-end reasoning goes from end to means, while means are actions that accordingly will realize the end (see Fig. 1).

The structure of means-end reasoning in relation to technology has been investigated to some extent. With its origin in von Wright's (1963) exploration of practical inference, J. Hughes (2009) suggests means-end reasoning fits well on the form of a syllogism:

Premise, q: Statement of a desire
Premise, $p \rightarrow q$: Statement of a means to attain the desire (belief)
Conclusion, p: Conclusion to act or intention to act to attain desire

Although this model is straightforward and effective, it does not encompass all endeavours of the design process. The second premise fails to reflect the complexity of the design process. Accordingly, there most often will be multiple means to achieve the desire. Hence, J. Hughes (2009) distinguishes between necessary, sufficient, and optimal means. The characteristics of the means will depend on the nature of the desire, and hence also on the nature of the design process. Thus, if there is a desire for a bridge, a necessary means would be to build a bridge. A bridge would not, however, be necessary for the desire of transportation over a body of water. It can be argued that there would not be any necessary means for attaining this. Hence, in cases where the desire is imprecise, there may only be sufficient means. Building a bridge would be a sufficient means for the desire of transportation over a body of water, but is it the best? This leads us to consider optimal means.

Determining the optimal means for transportation over a body of water is not immediately obvious. This depends on the context of where the design will operate. The context holds the answer to the question, optimal from what perspective? The understanding of where and for whom the design will be implemented lies in the context. That von Wright's (1963) model failed to account for this is a limitation, as also pointed out by Macagno and Walton (2018). This would have to be addressed through a more holistic model.

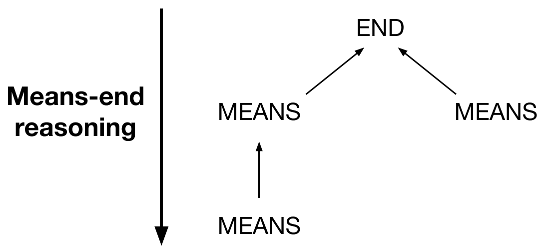


Fig. 1 Illustration of the flow of means-end reasoning

The desire for a holistic model for technology education

Following from the previous analysis of the literature on reasoning in the design process, the immediate observation is that all reasoning concepts and definitions share common grounds. J. Hughes' (2009) description of means-end reasoning seem not to be that far from Roozenburg's (1993) innoduction. In fact, de Vires (2012) states that means-end reasoning is abductive to its form. It appears the descriptions of the reasoning in design are in abundance, while a uniform form of the reasoning on macro- and micro-scale remains undetermined. As Dixon and French (2020, p. 8) put it:

> *… there is an evident lack of consensus across the macro-level and an insufficient level of evidence, as yet, available at the micro-level. Consequently, we take the view that it would not, at this point, be possible to make any definite claims regarding the logic of design or, indeed, the design reasoning process.*

As disheartening as this statement might be, one issue becomes clear. The view of the reasoning in design as being something different on macro- and micro-level, is problematic. Surely it is of interest to view the design process from these two perspectives, but that the reasoning would change on macro- and micro-level seem unnatural, stemming from the general view of reasoning as a process leading up to a conclusion. By departing from descriptions of reasoning types in the design process as conforming to the formal forms of reasoning; abductive, deductive, or inductive, a common model for the macro- and micro-level of design can be derived. Here, means-end reasoning accounts for the many reasonings processes that the design process consists of, where it is common for one conclusion to lead to the next, and the solving of one issue to generate new ones. In J. Hughes' (2009) description of means-end reasoning, means can be ends, and ends can generate new ends, until the final end is reached. In this way, means-end reasoning in the design process can be likened to a self-similar pattern of a fractal, which independent of scaling repeats itself endlessly. Thus, the design process consists of many means-end inferences on different scales.

Cause-effect reasoning as a means for a holistic model

Up until now, the view on the reasoning in design has been instrumental, where the goal seems to be to please one desire independent of what that desire is or what comes with it. It is, however, important in technology education that the students are supported and encouraged to take a step back and value the whole. Hence, a holistic approach is advocated in this model. This includes that "when one decides what to do, one should do so in the awareness that one's decision will have many aspects. One is therefore committed to accepting the whole story, including means, ends, side effects, and consequences" (Harman, 1986, p. 98). From this, three different types of cause-effect relationships can be identified (see Fig. 2). Firstly, there has to be a cause-effect relationship between means and end (von Wright, 1963), and the conclusion in the means-end reasoning should be based on a belief of such. At the same time, that means could bring about a side effect and the end might lead to other consequences in addition to the desired end. If we visit a simple example where we have the desire to tighten a nut. Tightening the nut with a wrench would be a means to that end. However, a side effect of using a

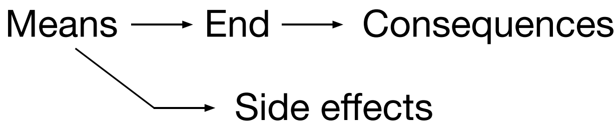


Fig. 2 Schematic illustration of the cause-effect relationships of means, end, side effects and consequences as interpreted from Harman (1986)

wrench is that the nut gets unnecessarily torn. Similarly, the consequence of a tightened nut is that it can be hard to unscrew. This might be a desired or an undesired consequence. The means-end reasoning in the design process should encompass premises of beliefs of these cause-effect relationships and these beliefs can originate from a different type of reasoning: *cause-effect reasoning*.

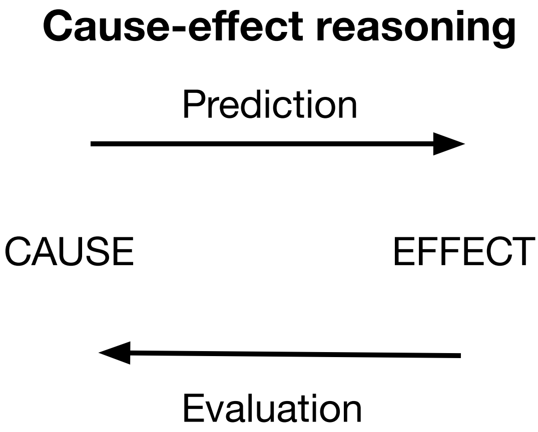
While means-end reasoning is reasoning that results in conclusions as actions or intentions to act, cause-effect reasoning results in conclusions as beliefs. In the design process it is important to form beliefs about consequences to make predictions of performance. Cause-effect reasoning can be used to establish beliefs of these relationships, if this – then that (de Vries, 2016a). To illustrate the use of cause-effect reasoning in the design process, let us consider the desire for a bridge again. If the context requires the bridge to have low maintenance, then it is important to carefully choose the appropriate material for the bridge. This requires reasoning about different materials, their properties, and their potential effects and it is through this cause-effect reasoning that we can form multiple beliefs about consequences of certain materials. de Vries (2016b) discusses reasoning in technology education and uses the example of the launch of space shuttle Challenger. The risks were known before the launch. Still, the space shuttle was launched, and the devastating catastrophe was evident. We can use the example of the design process of the space shuttles to illustrate cause-effect reasoning. During the design of the space shuttles, there were constant concerns being raised by engineers that specific O-rings did not function properly, especially under cold conditions. The material used for the O-rings had been specified to withstand high temperatures but not low (Roe et al., 1986). The cause-effect reasoning used to predict effects could have looked like this:

> The material for the O-rings has been prioritized to be able to handle high temperatures but cannot endure cold. So, if the launch of a space shuttle were to take place under low temperature conditions, the O-rings might not seal properly. Following this, the rockets, in addition to fuel tank and shuttle, could explode.

The conclusion in this reasoning is a belief about potential consequences, it is not a conclusion of how to act accordingly. The causes, low temperature, and temperature sensitive O-rings, result in an effect, and this prediction is made through cause-effect reasoning (see prediction in Fig. 3). The belief could be used in the subsequent means-end reasoning, where the conclusion of the action to redesign could be reached.

The process of prediction can also be reversed to evaluate in the design process (Jonassen & Ionas, 2008). This is of importance if the design process results in unpredicted side effects or consequences. The example of the catastrophe of the launch of Challenger would be an extreme but relevant example of a side effect of the means, temperature sensitive O-rings. Evaluating the causes of the catastrophic effect of the exploding space shuttle would be crucial, had it not been known to the engineers already. The flow of evaluating through cause-effect reasoning would then go from effect to cause (see evaluation in Fig. 3), which is relevant in technology education when, for example, testing prototypes.

Fig. 3 Illustration of the flow in cause-effect reasoning



This cause-effect reasoning can be compared to, but is not equal to, what Hempel and Oppenheim (1948) calls the scientific explanation, and which is often referred to as the deduction-nomological model. They describe prediction and explanation in science, which can be compared with this article's prediction and evaluation, while making no difference between prediction and explanation other than what is known from the beginning. In their seminal work they state four requirements for a scientific explanation, where one states that the deduction needs to contain general laws. General laws are often interpreted as natural laws, and in a later work by Hempel (1965) he states that these laws should not refer to specific objects or a specific space–time. In technology, a requirement of general laws is not necessary. In the example of the reasoning about Challenger, the premises containing rules such as "the material for the O-rings has been prioritized to be able to handle high temperatures but cannot endure cold" cannot be considered to contain any general laws. The rule is however useful and sufficient for drawing the conclusion. Thus, when predicting or evaluating through cause-effect reasoning in the design process the premise of a rule can be based on for example experience or experiments and does not necessarily have to include natural laws (e.g., Dym et al., 2005; Norström, 2013).

On the nature of premises

One important notion that has not yet been addressed is that relationships and believes can be of an uncertain or probabilistic nature, also in the design process. One can hold the belief that a certain means *might* or *probably will* lead to a desired result. Which is also why testing is such an important part in the design process. Such believes does not belong in formal reasoning. So, for a model of reasoning in the design process to be relevant, we must depart from the constraints of formal reasoning when defining reasoning. We still define reasoning as the process of reaching a conclusion using premises, but we widen the perspective of the nature of the premises and what premises to rely on. In design, the information or models used can be incomplete, which leaves the designer to lean on reasoning about uncertainty (Dym et al., 2005). This is also in line with a recent paradigm shift in psychology of reasoning. Evans et al. (2015) discusses the utility of *uncertain deduction* and argues that this is a form closer to the actual reasoning in everyday life problem-solving and decision making. To show an example of uncertain deduction, imagine a sailor out at sea that sees that the fair-weather cumulus clouds are growing vertically. The sailor knows that if the clouds are higher than they are wide at one o'clock in the afternoon, there is a chance for a thunderstorm in the evening, so she reasons:

Premise: If the clouds are higher than they are wide at one o'clock, there is a chance for a thunderstorm in the evening
Premise: The clouds are now higher than they are wide and its before one o'clock
Conclusion: There is a chance for a thunderstorm

Based on this belief, the sailor reasons that as she wants to be on the safe side. She reduces the sails later in the afternoon to avoid stresses in the rig and to sail safely through the possible approaching thunderstorm. This reasoning takes the form of a deduction but is by no means a formal deduction since the uncertainty in the first premise make the conclusion uncertain. It is, however, a useful way of reasoning. Based on the conclusion that there is a chance of a thunderstorm, the sailor can act accordingly. Although, there is a possibility that there might be no thunderstorm at all.

This type of reasoning can be very useful in the design process as well. For example, when designing boats, a rule of thumb is that the width to length ratio should be between 1:4 and 1:7, with sailboats needing to be relatively wide to be stable (Jensen, 2009). Thus, the means-end reasoning when determining width and length ratio might be as follows:

Premise: I want to make a stable sailing boat
Premise: For it to be stable a good width to length ratio is 1:4
Conclusion: I will make the boat four times longer than the width, then it will probably be stable

The key to this reasoning lays in the *qualifiers*, as Toulmin (2003) calls them. These qualifiers say something about to what degree the conclusion holds true. In the above examples, *a chance for* and *probably* work as qualifiers. It would have been invalid to conclude that there *will be* a thunderstorm or that the sailing boat *will be* stable based on the uncertainty in the premises. In the example with designing the sailing boat, there are additionally conclusions that will come into play for the boat to be stable.

This reasoning with uncertainty includes reasoning with heuristics. Heuristics can be described as rules of thumb that are useful in a certain context (Koen, 1985). The rule-premises in previous examples are examples of heuristics. These rules of thumb can originate from for example experience or scientific knowledge, and they do not have to be optimal. They can, however, be useful (Norström, 2011).

The previous example with width to length ratio, is an example of a means-end reasoning with heuristics. But heuristics can be used both in means-end reasoning and in cause-effect reasoning. Imagine trying to start a diesel engine, but it will not start. When having trouble starting a diesel engine, the rules of thumb are that it is either problem with the electric circuit or air in the fuel system. Since you hear the engine start but it comes to an immediate stop, it has probably nothing to do with electricity. So, you can conclude that the cause is probably air in the fuel system. This belief from a cause-effect reasoning is then useful in the means-end reasoning. You still want the engine to start, and it is probably air in the fuel system which can be remedied by venting, so you conclude to vent the fuel system. Thus, heuristics can be utilized within both means-end reasoning and cause-effect reasoning.

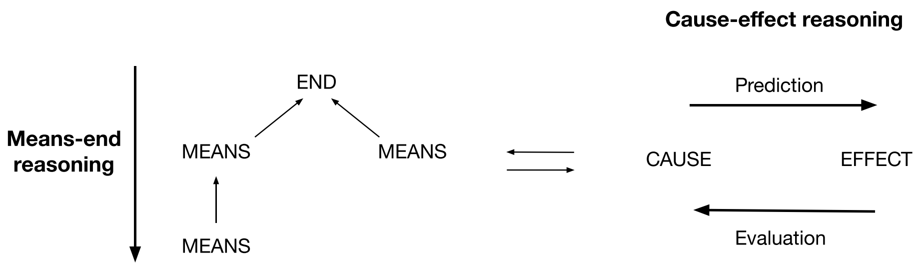


Fig. 4 Schematic illustration of means-end- and cause-effect reasoning and their interconnection

Table 3 Characteristics of means-end reasoning and cause-effect reasoning, established upon de Vries (2016a), Dym et al. (2005), Harman (1986), J. Hughes (2009), Jonassen and Ionas (2008), Norström (2011) and von Wright (1963)

Means-end reasoning	Cause-effect reasoning
Conclusion	
Action or intention to act	Belief about cause, effect, side-effect, consequence, or cause-effect relationship
Premises	
Stating end Rule based on belief of a cause-effect relationship of means and end Acknowledging relevant side-effects or consequences Can include uncertainty or heuristics	Stating cause or effect Rule linking cause and effect Can include uncertainty or heuristics

Presenting a holistic model for technology education

Following from the previous analysis, the conclusion is that a model of reasoning within the design process in technology education should consist of the two relevant types of reasoning, *means-end reasoning*, and *cause-effect reasoning*. There is a certain relationship between these reasoning types, and a student engaged in the design process would constantly go back and forth between them (see Fig. 4). Following from that one line of reasoning can inform the other and vice versa. These types of reasoning do not conform into one single form and can therefore not be prescribed as deductive, inductive, nor abductive. Formally the reasoning consists of premises and a conclusion. In the means-end reasoning the conclusion takes the form of an action or intention to act, while in the cause-effect reasoning the conclusion is a belief about cause, effect, side-effect, consequence, or a cause-effect relationship. In both reasoning types one premise takes the form of a rule stating a cause-effect relationship or linking cause and effect (see Table 3). Through cause-effect reasoning the students can predict side effects of means and consequences of ends, and by evaluating the whole, both the context and relevant values are considered within their reasoning. Thus, making this a holistic model for reasoning in the design process in technology education.

Valuing the whole in the design process involves placing the design in the context of where it will operate. Consequently, in the design process the context is something that especially affects the outcome. A solution to a problem in one context might be wrong in another. The American philosopher Andrew Feenberg emphasized that a study of technology should operate on two levels, where the technology is both decontextualized (primary level) and contextualized (secondary level) (Ankiewicz, 2019). This notion is in line with the STS-movement (Science-Technology-Society) in science and technology education, where the foundation is that these fields do not operate in isolation of each other. Thus, technology and society cannot be secluded from each other. Although, there has been some criticism towards the implementation of STS in education. G. Hughes (2000, p. 437) argued that as it is often used as "icing on the cake, not an essential basic ingredient" in science education the purpose is lost. Nevertheless, the design process in technology education provides a natural context for the teaching of values (Ankiewicz, 2019). Hence, within students' reasoning in the design process consideration to context and relevant values in this context should be made. Accordingly, the structure of the students' means-end reasoning can include premises concerning the context and values by including premises about relevant side-effects or consequences (see Table 3).

Application of the model in technology education

For the model to be explicitly presented, an example will follow of the model in use (see Table 4 and Fig. 5). To illustrate how the model can clarify students´ reasoning, we will show an example of a design process. In the example the reasoning types means-end reasoning and cause-effect reasoning are illustrated by premises followed by a conclusion. In technology education, the students learning about and from the design process can be centred around an assignment of creating a design that will fulfil a desire of their own. For instance, in the following example (see Table 4), a student has observed that their neighbours have trouble recycling. Through cause-effect reasoning the students can conclude what effect that will have (i). Followingly, this generates a desire, an end, to help the neighbours with this issue. But since the issues of recycling is unknown to the student, they conclude through a means-end reasoning to interview the neighbours (ii). Through more information about the issue and cause-effect reasoning, the student finds the cause of the problem (iii). This generates a new end – to make the instructions more comprehensible. Through a subsequent means-end reasoning, an idea of an app to help with the issue is concluded (iv). However, the students investigate possible side-effects of an app through cause-effect reasoning (v). Due to the side-effect and revisiting the final desire, the student decides through means-end reasoning to explore other options for their design (iv).

This example illustrates how the model can be used on students' reasoning in the design process. The student constantly alternates between means-end reasoning and cause-effect reasoning on their endeavor through the process. Both reasoning types advances the other (see Fig. 5), and this continues throughout the entire design process.

In this example, the reasoning takes place on a micro-level in the design process, where the student arrives at conclusions to act or intend to act based on premises. Analysing reasoning on this micro-level is suitable to make the student's process explicit, as difficulties are made visible (cf. Rittel, 1987). The reasoning on a macro-scale would predominately be visible when analysing the design process in retrospect, viewing the final design. However, in technology education, where students' learning is the objective, focusing on the reasoning on the micro-scale could be argued to be highly important.

Table 4 Example of a student's reasoning in the design process and application of model

	Student's reasoning		Model applied to the reasoning
i	I have noticed that a lot of people in my neighbourhood struggle with recycling. They sometimes mix materials. A single incorrect item can be enough to destroy the possibility to recycle a whole lorry of waste. Then that material does not get reused	Cause	I have noticed that a lot of people in my neighbourhood struggle with recycling.
		Rule	They sometimes mix materials. A single incorrect item can be enough to destroy the possibility to recycle a whole lorry of waste
		Effect	Then that material does not get reused
ii	I want the neighbours to be able to do it right, so I must ask them to know what the struggle is. I will start by interviewing my neighbours	End	I want the neighbours to be able to do it right,
		Rule	So I must ask them to know what the struggle is
		Means	I will start by interviewing my neighbours
iii	The neighbours say that it is not always that straight forward where to sort the materials, which is frustrating. Then it is easier to just guess. Frustration over the instruction leads them to guess. So, the instructions are probably too incomprehensible	Effect	The neighbours say that it is not always that straight forward where to sort the materials, which is frustrating. Then it is easier to just guess
		Rule	Frustration over the instruction leads them to guess
		Cause	So, the instructions are probably too incomprehensible
iv	According to my neighbours there is a need for comprehensible instructions of where to sort the items. An app could help with easy instructions. So I can create an app to help with the sorting	End	According to my neighbours there is a need for comprehensible instructions of where to sort the items
		Rule	An app could help with easy instructions
		Means	So I can create an app that could help with the sorting
v	The problem is that not all my neighbours have a smart-phones, and to use the app would require a smart-phone that can hold apps. So, if the instructions are on the app, they will not be accessible to everyone	Cause	The problem is that not all of my neighbours have a smart phone,
		Rule	and to use the app would require a smart phone that can hold apps
		Side-effect	So, if the instructions are on the app, they will not be accessible to everyone
vi	As I really want everybody to be able to recycle correctly, an app could help with that. However, an app will not be accessible to everyone. So, I do have to rethink the use of an app	End	As I really want everybody to be able to recycle correctly,
		Rule	an app could help with that
		Side-effect	However, an app will not be accessible to everyone
		Means	So, I do have to rethink the use of an app

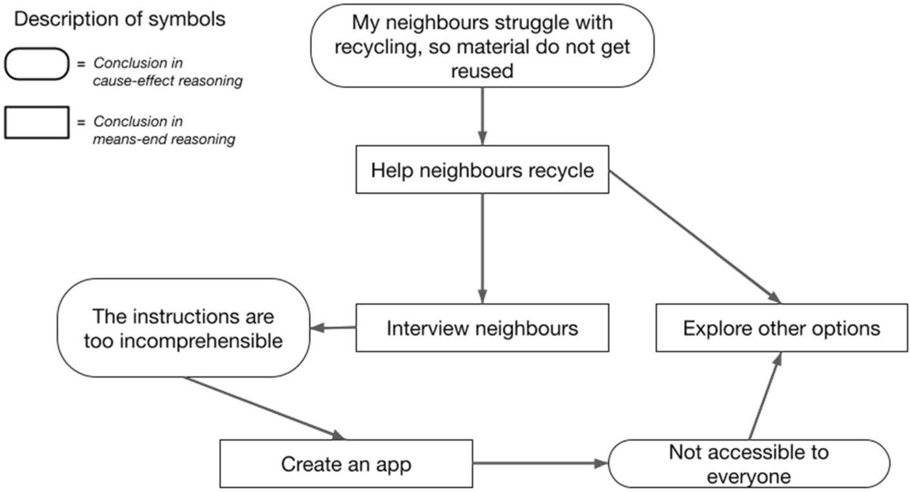


Fig. 5 Illustration of the flow of students means-end and cause-effect reasoning

Discussion

The model for reasoning in the design process in Technology Education presented here is an effort to describe and conceptualize students' reasoning in the design process. It provides a conceptual apparatus that can be used when analysing students' reasoning. When building the model, a consideration of limitations of previous models of reasoning has been made. Previous models (e.g., Dorst, 2011; Kroll & Koskela, 2016; Roozenburg, 1993) have struggled to grasp the reasoning in the design process on both macro- and micro-level, while other models (e.g., J. Hughes, 2009) have had an instrumental view of the reasoning. To account for this, the model describes and likens means-end reasoning to a self-similar fractal of inferences in the design process. Instead of instrumentalism, the model represents a holistic view, where side effects and consequences together as a whole are considered through cause-effect reasoning. These aspects of the model make it robust in the way that it is possible to use anywhere and anytime in the design process. Consequently, the model represents a general description of the reasoning in the design process in technology education.

On the same note, this is a model, with all the trade-offs that come with a model. For example, the authors have refrained from describing and conciliating the reasoning as formal forms of reasoning. This was deemed to have limited the usability of the model. Hence, the trade-off has been the level of detail to which the reasoning is described. Although, this is in line with the purpose of the model; to be used in research on students reasoning in the design process. However, a student reasoning in the design process would regularly go back and forth between the reasoning types. Furthermore, this intrinsic dance in addition to that Dusek (2006) points out that means-end and cause-effect are a reflection of each other, implies that the reasoning types may be hard to distinguish. Through future empirical research the view and structure of the reasoning can unravel and thus this model is a starting point.

Within the literature the prefixes of reasoning are in abundance. In New Zealand focus has been on functional reasoning and practical reasoning as moral reasoning (Compton, 2019; Ministry of Education, 2018). de Vries (2016b) distinguishes ethical- and aesthetic reasoning. On the same note, Daugherty and Mentzer (2008) focus on analogical reasoning. These prefixes say something about what the reasoning is about, and this model does not exclude such reasoning. On the contrary, the model encompasses all these different types of reasoning. If for example, the students reason about functions in their means-end reasoning this would be a functional reasoning as well. The same can be concluded about ethical-, aesthetic- and moral reasoning and so on. In the design process all this reasoning will, through means-end reasoning, lead up to an action or a conclusion not to act – which is an action as well.

Describing and making the grounds explicit in the students reasoning in the design process, as in this model, might in the end benefit the students individually, as the basis for drawing conclusions is made visible and accessible. The example in Table 4 is not a complete example of the reasoning in the design process. It illustrates that starting from even the simplest of desires, the thought process and its representations in the design process quickly becomes complex and volatile. Framing this reasoning is an asset to the teachers making sense of students' actions and expressed beliefs. Their guiding and scaffolding of their students' learning can be supported through insights into what reasoning the students are expressing, as also emphasized by Seery et al. (2022). Followingly, teachers can propel students to develop their reasoning in design. Being able to function and make decisions in a world where technology is constantly present includes reasoning within it (Rossouw et al., 2011). Situating this reasoning in the design process may increase students' ability to critically examine the technology that surrounds them. The aim of the model is to provide a holistic model which could promote students' insights into how technology operates in complex contexts and how consideration of it should be made.

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References

Alamäki, A. (2000). Technological reasoning as a human side of technological innovation. In *Innovation and Diffusion in Technology Education: Proceedings of PATT-10 Conference* (pp. 9–15). PATT.

Ankiewicz, P. J. (2019). Andrew Feenberg: Implications of critical theory for technology education. In J. R. Dakers, J. Hallström, & M. J. de Vries (Eds.), *Reflections on Technology for Educational Practitioners* (pp. 115–130). Brill Sense.

Autio, O., & Soobik, M. (2017). Technological knowledge and reasoning in Finnish and Estonian technology education. *International Journal of Research in Education and Science, 3*(1), 193–202.

Buckley, J., Seery, N., Canty, D., & Gumaelius, L. (2018). Visualization, inductive reasoning, and memory span as components of fluid intelligence: Implications for technology education. *International Journal of Educational Research, 90*, 64–77.

Citrohn, B., Stolpe, K., Svensson, M., & Bernard, J. (2022). Affordances of models and modelling: A study of four technology design projects in the Swedish secondary school. *Design and Technology Education: An International Journal, 27*(3), 58–75.

Compton, V. (2019). Günter Ropohl: Supporting a technological literacy for future citizenship. In J. R. Dakers, J. Hallström, & M. J. de Vries (Eds.), *Reflections on Technology for Educational Practitioners* (pp. 37–54). Brill Sense.

Cramer-Petersen, C. L., Christensen, B. T., & Ahmed-Kristensen, S. (2019). Empirically analysing design reasoning patterns: Abductive-deductive reasoning patterns dominate design idea generation. *Design Studies, 60*, 39–70.

Daugherty, J., & Mentzer, N. (2008). Analogical reasoning in the engineering design process and technology education applications. *Journal of Technology Education, 19*(2), 7.

de Vries, M. J. (2012). Philosophy of technology. In P. J. Williams (Ed.), *Technology Education for Teachers* (pp. 15–33). Brill Sense.

de Vries, M. J. (2016a). A philosophical basis for pre-university engineering education. In M. J. de Vries, L. Gumaelius, & I. B. Skogh (Eds.), *Pre-University Engineering Education* (pp. 13–25). Brill Sense.

de Vries, M. J. (2016). *Teaching About Technology: An Introduction to the Philosophy of Technology for Non-philosophers*. Springer.

Dixon, B., & French, T. (2020). Processing the method: Linking Deweyan logic and design-in-research. *Design Studies, 70*, 100962.

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies, 32*(6), 521–532.

Dusek, V. (2006). *Philosophy of Technology: An Introduction*. Blackwell.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120.

Evans, J. S. B., Over, D. E., & Manktelow, K. I. (1993). Reasoning, decision making and rationality. *Cognition, 49*(1–2), 165–187.

Evans, J. S. B., Thompson, V. A., & Over, D. E. (2015). Uncertain deduction and conditional reasoning. *Frontiers in Psychology, 6*, 398.

Harman, G. H. (1965). The inference to the best explanation. *The Philosophical Review, 74*(1), 88–95.

Harman, G. (1986). *Change in View: Principles of Reasoning*. The MIT Press.

Hempel, C. G. (1965). *Aspects of Scientific Explanation: And Other Essays in the Philosophy of Science*. Free Press.

Hempel, C. G., & Oppenheim, P. (1948). Studies in the logic of explanation. *Philosophy of Science, 15*(2), 135–175.

Hughes, G. (2000). Marginalization of socioscientific material in science–technology–society science curricula: Some implications for gender inclusivity and curriculum reform. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 37*(5), 426–440.

Hughes, J. (2009). Practical reasoning and engineering. In A. Meijers (Ed.), *Philosophy of Technology and Engineering Sciences* (pp. 375–402). North-Holland.

Jensen, J. K. (2009). *Haandbog i Praktisk Sömansskab [Handbook of Practical Seamanship]* (4th ed.). Høst & Søn.

Jonassen, D. H., & Ionas, I. G. (2008). Designing effective supports for causal reasoning. *Educational Technology Research and Development, 56*(3), 287–308.

Koen, B. V. (1985). *Definition of the Engineering Method*. ASEE Publications.

Kolko, J. (2010). Abductive thinking and sensemaking: The drivers of design synthesis. *Design Issues, 26*(1), 15–28.

Kroes, P. (2009). Foundational issues of engineering design. In A. Meijers (Ed.), *Philosophy of Technology and Engineering Sciences* (pp. 513–541). North-Holland.

Kroes, P. (2012). *Technical Artefacts: Creations of Mind and Matter*. Springer.

Kroll, E., & Koskela, L. (2016). Explicating concepts in reasoning from function to form by two-step innovative abductions. *AI EDAM, 30*(2), 125–137.

Macagno, F., & Walton, D. (2018). Practical reasoning arguments: A modular approach. *Argumentation, 32*(4), 519–547.

March, L. (1976). The logic of design. In L. March (Ed.), *The Architecture of Form* (pp. 16–40). Cambridge University Press.

Ministry of Education. (2018). Technology in the New Zealand curriculum. Retrieved 26 January 2023 from http://nzcurriculum.tki.org.nz/The-New-Zealand-Curriculum/Technology.

Norman, D. (2013). *The Design of Everyday Things: Revised and Expanded Edition*. Basic books.

Norström, P. (2011). Technological know-how from rules of thumb. *Techne: Research in Philosophy & Technology, 15*(2), 9966.

Norström, P. (2013). Explanation and prediction in technology education. In I. B. Skogh & M. J. de Vries (Eds.), *Technology Teachers as Researchers: Philosophical and Empirical Technology Education Studies in the Swedish TUFF Research School* (pp. 33–51). Springer Science & Business Media.

Norström, P. (2016). The nature of pre-university engineering education. In M. J. de Vries, L. Gumaelius, & I. B. Skogh (Eds.), *Pre-University Engineering Education* (pp. 27–46). Brill Sense.

Quintana-Cifuentes, J. P. (2022). *Studying Design Reasoning in Problem Framing Using the Design Reasoning Quadrants Framework.* [Doctoral dissertation, Purdue University].

Rittel, H. W. J. (1987). The reasoning of designers. *International Congress on Planning and Design Theory., 12*, 56966.

Roe, R. A., Brown, G. E., Scheuer, J. H., Lloyd, M., Wirth, T. E., Walgren, D., Glickman, D., Young, R. A., Volkmer, H. L., Nelson, B., Lundine, S., Hall, R. M., McCurdy, D., Mineta, N. Y., MacKay, B., Valentine, T., Reid, H. M., Torricelli, R. G., Boucher, R., & Monson, D. S. (1986). *Investigation of the Challenger Accident: Report of the Committee on Science and Technology*. US government printing office.

Roozenburg, N. F. (1993). On the pattern of reasoning in innovative design. *Design Studies, 14*(1), 4–18.

Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education, 21*(4), 409–424.

Seery, N., Phelan, J., Buckley, J., & Canty, D. (2022). Epistemological treatment of design in technology education. *International Journal of Technology and Design Education, 4*, 1–15.

Skolverket (2022). *Läroplan för grundskolan, förskoleklassen och fritidshemmet 2022 [Curriculum for the Compulsory School, Preschool Class and School-age Educare 2022]*. Skolverket.

Thorsteinsson, G., & Olafsson, B. (2016). Piloting technological understanding and reasoning in Icelandic schools. *International Journal of Technology and Design Education, 26*(4), 505–519.

Toulmin, S. E. (2003). *The Uses of Argument*. Cambridge University Press.

von Wright, G. H. (1963). Practical inference. *The Philosophical Review, 72*(2), 159–179.

Walton, D. N. (1990). What is reasoning? What is an argument? *The Journal of Philosophy, 87*(8), 399–419.

Weber, E., Wouters, D., & Meheus, J. (Eds.). (2014). *Logic, Reasoning, and Rationality* (Vol. 5). Springer.

Wikberg-Nilsson, Å., Ericson, Å., & Törlind, P. (2021). *Design: Process och metod [Design: Process and Method]* (2nd ed.). Studentlitteratur AB.