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Information acquisition in Adapt/Exchange decisions: When do people check alternative solution principles?

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Many problems can be solved in two ways: either by adapting an existing solution or by exchanging it for a new one. To investigate under what conditions people consider new solutions, we traced their information acquisition processes in a simulated mechanical engineering task. Within a multi-step optimisation procedure, participants could either adapt the properties of a currently used machine component or exchange this component for a new one. They had the opportunity to check whether the solutions met a set of requirements, which was manipulated between trials. We investigated whether participants would thoroughly check both solutions or ignore the new solution as long as the current one was good enough (i.e., satisficing). The results clearly refuted consistent checking of both solutions, but only partly confirmed satisficing. On the one hand, participants indeed checked the new solution least often when the current one was applicable without problems. On the other hand, in this case the new solution still was not fully ignored. However, the latter finding could be traced back to a few participants who diverged from our anticipated strategy: Instead of first checking the current solution, they directly went for the new one. Taken together, the results suggest that in Adapt/Exchange decisions, people do not usually check both solutions in an unbiased manner, but rely on existing solutions as long as they are good enough.

Keywords: decision-making, Adapt/Exchange decisions, information acquisition, information costs, cross-checking, heuristics, satisficing

How do problem solvers decide whether to stick with existing solutions or flexibly consider new ones? The trade-off between stability and flexibility has received ample empirical attention in cognitive psychology (Chrysikou et al., 2014; Goschke, 2013; Hommel, 2015). It is commonly observed that flexibility is rather limited: People often stick with previous choices or defaults (Betsch et al., 2002; Dutt & Gonzalez, 2012; Erev et al., 2010; Jachimowicz et al., 2019; Johnson & Goldstein, 2003; Rakow & Miler, 2009; Samuelson & Zeckhauser, 1988; Scherbaum et al., 2013; Senftleben et al., 2019). However, stability-flexibility trade-offs were quite simple in most psychological studies as participants merely had to decide whether to make a change or not. Conversely, many real-world problems require decision-makers to choose between different types of changes. When an existing solution no longer produces satisfactory outcomes, you can either modify its details (Adapt), or apply a fundamentally different solution principle (Exchange) (Müller & Urbas, 2017). For instance, when mechanical engineers re-design a machine, they can either adapt a currently used component (e.g., change its dimensions) or replace it by a completely new component that fulfills the same function but might overcome the shortcomings of the current component. In complex systems, an exhaustive exploration of all potential solutions is rarely possible, so problem solvers rely on less resource-demanding strategies and heuristics (Fischer et al., 2012; Schoppek, 2023). Thus, they might simply adapt previous solutions as long as they still are good enough, without thoroughly acquiring information about new solutions. This corresponds to the well-known strategy of satisficing (Simon, 1956). While being highly efficient, it can keep problem solvers from discovering that new solutions may lead to better outcomes.

In the present study, we investigated under what conditions people rely on existing solutions without checking alternatives when making Adapt/Exchange decisions. In the following sections, we will (1) describe the characteristics of Adapt/Exchange decisions, (2) discuss why previous Adapt/Exchange studies do not provide conclusive evidence about the underlying information acquisition processes, (3) review research about information acquisition in other decision contexts, and (4) explain how the present study investigates information acquisition processes in Adapt/Exchange decisions.

Adapt or Exchange: decisions within an abstraction hierarchy

Adapt/Exchange decisions differ from the decisions typically studied by psychologists in interesting ways (for a detailed discussion see Müller & Urbas, 2020). Most importantly, the two options are different means of achieving one and the same abstract goal. Complex systems can be conceptualised in a *hierarchy of functional abstraction* (Naikar, 2017; Rasmussen, 1985). That is, they can be described with regard to either their purposes, the functions carried out to achieve these purposes, the components realising these func-

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tions, or the properties characterising these components. Higher levels of abstraction define *why* something is needed, whereas lower levels define *how* it is implemented. Basically, Adapt/Exchange decisions reflect whether problem solvers move up in the abstraction hierarchy when selecting solutions. Figure 1 illustrates this principle by using the example of a packaging machine. The purpose of such a machine might be to maximise the output of products packaged per time unit. This can be achieved by combining different abstract functions or product handling tasks, such as transporting, filling, and forming (Bleisch et al., 2011). Each of them can be specified further. For instance, transporting can mean that the product needs to be turned. Ultimately, functions are realised by physical machine components. For instance, a product can be turned via a turnover wheel or a turnover belt. These components have properties, such as their dimensions and the materials they are made of.

Successful problem solving requires a *flexible navigation between these levels of abstraction* (Hall et al., 2006; Janzen & Vicente, 1998). Especially when problems are complex, it is beneficial to move up in the hierarchy (Ham & Yoon, 2001). This is because increasing abstraction allows people to find suitable alternatives when problems cannot be solved by merely modifying the details of the current solution (Hajdukiewicz & Vicente, 2002). However, people may not always be so flexible: Instead of considering an exchange of the solution principle, they often try to make minor adaptations to it. This reluctance to consider fundamental changes can lead to characteristic biases such as *design fixation* (Alipour et al., 2018; Youmans & Arciszewski, 2014). This phenomenon occurs when people remain focused on a product's physical implementation, while being unable to revisit the more general ideas underlying this implementation (Jansson & Smith, 1991). Various cognitive mechanisms of design fixation have been elaborated, such as unconscious adherence, conscious blocking, or intentional resistance (for an overview see Youmans & Arciszewski, 2014).

The work and creative processes of expert designers as well as the challenges arising in this process have been described in many insightful studies (e.g., Ahmed et al., 2003; Badke-Schaub, 2004; Cross, 2004; Hacker et al., 1998). For instance, designers may collect too little information and instead proceed to the generation of solutions too early (Bursic & Atman, 1997; Christiaans & Dorst, 1992) or narrowly focus on a known, available solution too early (Ball et al., 1994; Fricke, 1996; Ullman et al., 1988). However, such expert strategies and challenges are not the focus of the present study. Instead, we are using a highly simplified, simulated design task as a tool to study the decision-making of non-expert participants. This is because we believe it is beneficial to complement typical lab studies on decision-making (which often use abstract stimuli such as lotteries) by studies that rely on real-world problem structures. Still, this will not allow us to infer what expert designers are doing – a limitation that we will revisit in the Discussion. In the present study, our aim is to investigate ordinary people's *processes of information acquisition* in Adapt/Exchange decisions. This is because previous research suggests that people might not always seek out information about new solutions, as discussed in the following section.

Previous Adapt/Exchange studies do not provide conclusive evidence about information acquisition

Two previous studies on Adapt/Exchange decisions suggest that people do not consider both solution principles equally and thoroughly (Müller, 2024; Müller & Urbas, 2020). In one study, participants had to solve problems in a chemical process control scenario (Müller & Urbas, 2020). They could either modify process parameters such as pressure and temperature (Adapt) or reconfigure the plant and use a more suitable reactor (Exchange). Participants seemed to refrain from checking the consequences of exchanging the solution as long as adapting it was good enough. Such satisficing was inferred from two findings. First, the frequency of Exchange choices depended on the costs of Adapt, instead of on the cost ratio between Adapt and Exchange. Second, Adapt choices were much faster than Exchange choices, suggesting that the latter included an additional cognitive process (i.e., checking the alternative solution) that was otherwise omitted. This conclusion was corroborated in another study that used the same scenario but varied the format of information presentation (Müller, 2024). Participants' choice patterns suggested that they refrained from comparing the two solutions especially when information integration was difficult. However, these observations only provide very indirect evidence for satisficing, because participants' actual information acquisition processes were not monitored. This limitation is overcome in the present study. Before describing the experimental setup, the following section will discuss what we can learn about information acquisition strategies from research in other decision contexts.

How do decision-makers acquire information about potential solutions?

Several lines of decision-making research have investigated how people collect and integrate information before making a choice. In this section, we will review some of them, and compare the structures of the problems they studied to those of Adapt/Exchange decisions. This allows us to assess what inferences we can draw about information acquisition in Adapt/Exchange decisions.

A first line of related research is *multi-attribute decision-making*, where people choose between several options (e.g., different houses) that differ in several attributes (e.g., location, price, connection to public transport). People typically do not consider and integrate all attributes, but instead use simpler heuristics (Bettman et al., 1993; Payne et al., 1988), especially

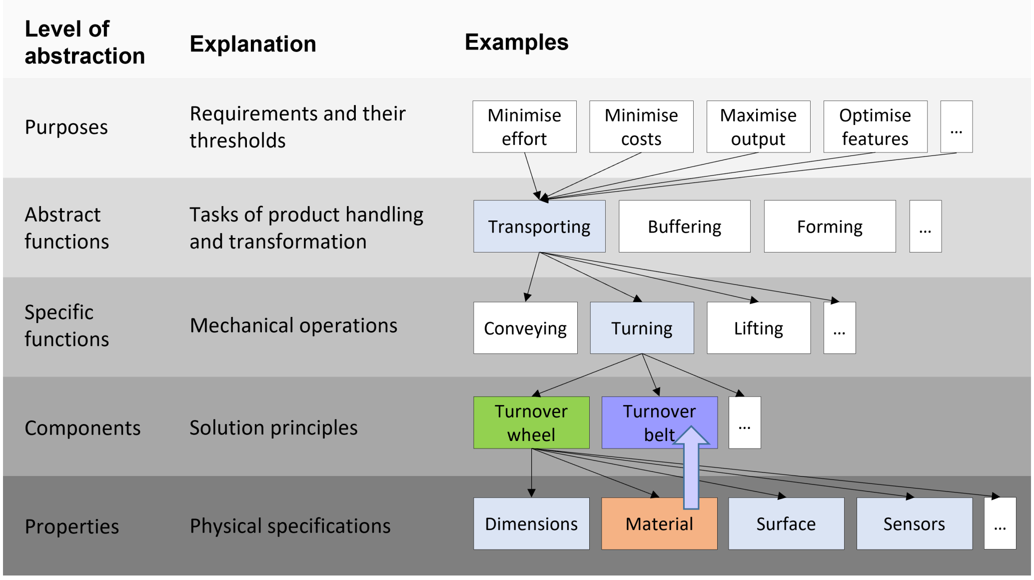

Figure 1. Implementation of the abstraction hierarchy in the present study. When adapting the current solution (e.g., turnover wheel) by modifying its properties (e.g., material) does not meet the requirements, problem solvers need to move up in the hierarchy and reconsider the solution principle as such, in this case by exchanging the type of component (e.g., using a turnover belt instead).

when interpreting or integrating the information is effortful (Glöckner & Betsch, 2008; Söllner et al., 2013). However, note that in multi-attribute decision-making, limited information acquisition usually pertains to attributes rather than options – people rarely ignore an option as a whole. Thus, the problem structure differs from that of Adapt/Exchange decisions, where we assume that people might refrain from checking one of only two solutions altogether.

Another related line of research has investigated under what conditions people stop their information search once an option is good enough – a strategy referred to as *satisficing* (Simon, 1956, 1990). Although satisficing is considered a heuristic, it can be a highly reasonable strategy in complex environments (Todd et al., 2012). It typically occurs when the number of options is excessive or unknown (Gigerenzer et al., 2012; Todd & Gigerenzer, 2007; Todd & Miller, 1999). For instance, when choosing a spouse, people cannot possibly consider all options (Todd & Miller, 1999). To date, it is unclear whether satisficing also occurs when the number of options is as low as in Adapt/Exchange decisions, where the choice is often restricted to only two solutions. Our previous studies (Müller, 2024; Müller & Urbas, 2020) suggest that it can occur, but given that we only observed indirect evidence for satisficing (based on performance data), we might have misinterpreted these observations.

Satisficing might still be an issue with only two options, namely when the *costs of information acquisition* are high. The higher the costs of evaluating an option, the fewer options are considered (Hauser & Wernerfelt, 1990). Recently, studies have begun to systematically examine how decision-makers trade off the costs and benefits of information acquisition when they are free to sample as much information about an option as they consider appropriate (Fiedler et al., 2021; McCaughey et al., 2023). These sampling studies have observed a striking tendency to over-sample. Participants did not seem to consider that collecting more information was less conducive to accuracy than it was detrimental to speed, thereby reducing overall payoffs. These observations are in line with a general tendency of participants in psychological studies to prioritize accuracy over efficiency (Fiedler & McCaughey, 2023). Thus, in Adapt/Exchange decisions, people might also consistently check the alternative solution, even when the current solution is feasible and information acquisition is costly. However, in sampling studies participants encounter two parallel options, while in Adapt/Exchange decisions the Adapt solution reflects the status quo and thus might be more dominant to begin with (cf. Samuelson & Zeckhauser, 1988). How do people trade off the costs and benefits of information acquisition when choosing between a dominant and a non-dominant solution?

This situation is somewhat similar to that in Human Factors studies on the use and misuse of *decision support systems*. When such systems offer a solution, do people directly accept it, or do they carefully cross-check its validity? The evidence is mixed. On the one hand, a myriad of studies reported evidence of automation bias, showing that people over-rely on automated suggestions without cross-checking (for reviews see Mosier & Manzey, 2019; Onnasch et al., 2014; Parasuraman & Manzey, 2010). On the other hand, sometimes people do cross-check suggestions quite thoroughly, for instance when diagnosing and solving machine problems (Müller et al., 2019) or when verifying the validity of alarms (Manzey et al., 2014). The task features that determine wheter people simply accept or cross-check automated suggestions are yet to be clarified (for a discussion see Müller et al., 2019). Still, in line with the sampling studies discussed above, people sometimes have a strong preference for accuracy, despite substantial costs of information acquisition.

Taken together, previous research on information acquisition in decision-making has painted a mixed picture. On the one hand, people usually do not collect and integrate all available information when choosing between multiple options, especially when information integration is effortful and when the number of available options is excessive or unknown. Such limited information acquisition might also be expected in Adapt/Exchange decisions with only two options when information acquisition is costly. However, people often incur substantial costs for the sake of making slightly more accurate decisions. Thus, one might alternatively infer that they will also scrutinise the alternative solution, even when the current solution is feasible. To differentiate between these possible strategies empirically, an experimental setting is needed that allows us to trace people's information acquisition processes.

Present study

Research questions end experimental setting

The present study investigated under what conditions people check alternative solutions in Adapt/Exchange decisions. Do they consistently engage in a thorough comparison of both solutions or do they refrain from checking Exchange when Adapt is good enough? We addressed this question in a simulated and highly simplified mechanical engineering task. Participants had to select and specify a machine component for turning a chocolate bar in a wrapping machine. This function could be realized by two different solution principles presented in a decision support system. One of these solution principles was a previously used component and participants could modify its physical properties (Adapt), whereas they were instructed that the alternative solution (Exchange) had to be constructed from scratch. However, this additional construction process was only hypothetical and not part of the experimental procedure, which was identical for both solutions.

The task goal was to find a good solution with respect to different requirements such as costs and output, without unnecessarily wasting construction time. Thus, there were multiple constraints to be satisfied and participants were free to weight them according to their own preferences, while staying within certain explicitly defined limits. The two solution principles had complementary benefits and costs. For Adapt, no additional construction time was needed, but it was unclear whether the current solution could meet all requirements. Conversely, the new Exchange solution was guaranteed to meet these requirements, but constructing it would take considerable time. Participants did not know in advance whether this extra time was worth spending – that is, whether Adapt was feasible and whether Exchange would result in a better machine. They were able to find this out by actively seeking out information about the two solutions. To this end, they performed a multi-step optimization procedure (for an overview see Figure 3). First, they had to select which solution they wanted to check and specify (e.g., adapt the current turnover wheel, exchange it for a turnover belt). Second, they had to check the feasibility and quality of this solution in four steps of specifying its physical properties (e.g., size of the turnover wheel). To this end, they had to check which of two versions of the respective property (e.g., two sizes) performed better on four requirements (i.e., effort, costs, output, physical features). To achieve this, they had to compare the versions' numerical goal achievement values (e.g., their costs) to a fixed requirement threshold (e.g., maximum acceptable cost). After this process of checking and specifying was completed, participants could either confirm their solution or check the other solution principle (e.g., exchange the turnover wheel for a turnover belt).

Our aim was to examine how the frequency of checking Exchange depended on whether Adapt was good enough. Therefore, we manipulated the feasibility of both solutions between trials. The feasibility of Adapt reflected whether the requirements could be met by merely adapting the current component (see Table 1). Thus, participants could only find out whether Adapt was feasible by checking all of its properties. Adapt could either be non-problematic, meaning that it met all requirement thresholds (henceforth referred to as

Table 1. Five types of solution feasibility with their labels and explanations for Adapt and Exchange. Selecting a solution with a "+" or "(–)" sign is a valid choice, while selecting a solution with a "–" sign is an error.

Author	Goal/Objectives	Effects
A–E+	Global problem: a global threshold on one requirement is not met after specifying all properties	No problem: required construction time is shorter than time to deadline
A(–)E+	Local problem: a local threshold on one requirement is not met for one property	No problem: required construction time is shorter than time to deadline
A(–)E–	Local problem: a local threshold on one requirement is not met for one property	Scheduling problem: required construction time is longer than time to deadline
A+E+	No problem: all thresholds are met	No problem: required construction time is shorter than time to deadline
A+E–	No problem: all thresholds are met	Scheduling problem: required construction time is longer than time to deadline

A+), locally problematic in the sense that it failed to meet a local requirement threshold for one property but still met the global requirement threshold at the end of the trial (A(–)), or globally problematic in the sense that it also failed to meet this global threshold (A–). Local problems were undesirable but acceptable, whereas global problems rendered Adapt impossible. Exchange always met all local and global requirement thresholds, as this is the very purpose of exchanging the solution principle. Instead, the feasibility of Exchange depended on whether the new component could be constructed before the scheduled delivery deadline (E+) or not (E–). This was already known at the start of a trial and did not require any extra checking. Checking Exchange could still be useful, because the two solutions reached different point scores with regard to the requirements, determining which one was numerically better. However, checking Exchange never was mandatory, because as long as no global problems (A–) or scheduling problems (E–) were present, either solution was a valid choice.

Hypotheses

Information acquisition. When do people check the alternative solution in Adapt/Exchange decisions? The present study aimed to distinguish between four general strategies: no checking, consistent checking, and two versions of a satisficing strategy. While we do not consider it plausible that all participants adopt the same strategy, we aimed to investigate whether particular strategies are more common than others in the present scenario. In addition to testing four hypotheses that differentiate between the four strategies, we also performed an exploratory, qualitative analysis describing the variety of individual information sampling approaches adopted by different participants.

The four strategies we investigated were tested against the following two baselines: We generally assumed that participants rarely check Exchange when it is ruled out in advance by a scheduling problem (E–) and that they consistently check Exchange when Adapt is ruled out by a global problem (A–). Accordingly, these conditions served as an upper and lower baseline, respectively. If participants refrain from checking and choosing the respective non-feasible solutions, this can be considered a form of manipulation check, suggesting that participants neither misunderstood nor re-interpreted the task constraints.

In principle, one conceivable outcome is what we will call the *no-checking strategy.* It rests on the literature on automation bias, reporting that people uncritically accept the solutions suggested by decision support systems (Mosier & Manzey, 2019; Onnasch et al., 2014; Parasuraman & Manzey, 2010). Similarly, they might accept Adapt without checking its feasibility, and thus also have no need to check Exchange. In this case, Exchange checking rates should not differ from the lower baseline, regardless of Adapt feasibility. This leads to the testable hypothesis (*H1*) that A–E+, A(–)E+, and A+E+ neither differ from A+E–, nor from each other. However, we considered this hypothesis highly unlikely, as the present task structure clearly differed from that of typical studies on automation bias.

The second possible outcome will be referred to as the *consistent-checking strategy.* It rests on the observation that people have a strong bias for accuracy, and thus thoroughly acquire information even when it is costly and the achievable gains are minimal (Fiedler et al., 2021; Manzey et al., 2014; Müller et al., 2020; Müller et al., 2019). Accordingly, participants should be highly motivated to find out which solution reaches a higher point score, and therefore check both solutions unless the alternative is ruled out in advance (E–). Thus, similar to the no-checking strategy, the frequency of checking Exchange would not depend on Adapt feasibility, but it should be similar to the upper instead of the lower baseline. Translated into a testable hypothesis (*H2*), A(–)E+, and A+E+ should neither differ from each other, nor from A–E+.

The strategy we considered most likely was that people satisfice when making Adapt/Exchange decisions (Müller, 2024; Müller & Urbas, 2020). This satisficing strategy comes in two versions. The *weak satisficing strategy* implies that Exchange checking decreases as Adapt feasibility increases. In this case, the corresponding testable hypothesis (*H3*) is that most Exchange checking occurs when Adapt is globally problematic (A–E+), less when Adapt is locally problematic (A(–)E+), and even less when Adapt is non-problematic (A+E+). The *strong satisficing strategy* implies that participants do not check Exchange whenever Adapt is good enough. Thus, the testable hypothesis (*H4*) corresponding to strong satisficing is that when Adapt is non-problematic, the frequency of checking Exchange does not differ between trials in which Exchange is possible (A+E+) versus impossible (A+E–, lower baseline).

While the first two strategies (no checking and consistent checking, *H1* and *H2*) are mutually exclusive and also cannot coexist with satisficing (*H3* and *H4*), the two versions of the satisficing can coexist. Moreover, weak satisficing (*H3*) has a higher a priori likelihood than strong satisficing (*H4*). This is because the former only assumes that the quality of Adapt (A+ vs. A(–) vs. A–) modulates Exchange checking, whereas the latter makes the somewhat extreme prediction that, given a high quality of Adapt (A+), people do not check the alternative any more often when they might gain something from this checking (E+) than when it is clear in advance that they will not gain anything because the alternative solution is impossible to implement, anyway (E–). Thus, if the data supported strong satisficing, this would provide compelling evidence that people refrain from checking alternative solutions as long as the current one is good enough.

Choice. In addition to participants' information acquisition behaviour, we also analyzed their rates of choosing Exchange. Regardless of whether the information acquisition results would support the consistent-checking strategy or either version of the satisficing strategy, we expected the same data pattern: participants' choices should reflect the different levels of Adapt and Exchange feasibility. That is, we expected most Exchange choices when Adapt was globally problematic (A–), fewer when it was locally problematic (A(–)), and fewest when it was non-problematic (A+). Similarly, we expected more Exchange choices when Exchange was non-problematic (E+) than when it was ruled out by a scheduling problem (E–). Thus, regardless of participants' information acquisition behaviour, we expected their choice patterns to resemble the information acquisition pattern of the weak satisficing strategy. Finally, we expected a general increase in Exchange choices when it reached a higher point score than Adapt, but had no hypotheses about interactions of this factor with solution feasibility.

Exploratory analyses of individual strategies. We intended to assess inter-individual differences in participants' information acquisition strategies in an exploratory manner. Specifically, we looked at the order in which participants would check the two solutions (i.e., which solution is checked first, and whether solutions are checked repeatedly).

Methods

Data availability

All stimuli, instructions, human participant data, and syntax files are made available via the Open Science Framework: `https://osf.io/53yd4/`

Participants

Twenty-five members of the TUD Dresden University of Technology participant pool (ORSEE, Greiner, 2015) took part in the study in exchange for course credit or 8€ per hour. No participant had to be excluded, because all achieved the required score in a knowledge test before the experiment. The sample included 17 female and 8 male participants, and their age ranged from 18 to 45 years ($M = 26.4$, $SD = 6.4$). Participants provided written informed consent and all procedures followed the principles of the Declaration of Helsinki.

Apparatus and stimuli

Lab setup

Experiments took place in a quiet lab room, using one of two desktop computers (monitor sizes 24") for stimulus presentation as well as a standard QWERTZ keyboard and computer mouse as input devices. The experimental procedure was programmed with the Experiment Builder (SR Research, Ontario, Canada, Version 2.2.61).

Instruction video and knowledge test

Before the experiment, participants watched a 22 minutes instruction video based on a Microsoft PowerPoint presentation. In the first part, the scenario was introduced. Participants were informed that they would play the role of an engineer choosing a component for turning a chocolate bar in a wrapping machine. The video explained that two solution principles were available (i.e., turnover wheel, turnover belt), and how each could be specified regarding four properties (i.e., dimensions, material, surface, sensors) to meet four requirements (i.e., effort, costs, output, physical features). The second part of the video was a step-by-step demonstration of the experimental procedure, presenting the consecutive screens of an example trial. The contents of each screen were described and participants were shown which actions they could perform. However, no strategies were suggested. In the demonstration, Adapt was selected. Participants were informed that they could go back and check out Exchange as well (following the same procedure), but this procedure was not shown again.

A paper-and-pencil knowledge test was administered to identify participants with insufficient understanding of the instruction. This test consisted of 10 multiple-choice questions with four response alternatives, only one of which was correct for each question. A cut-off of 90% correct answers was used to determine whether a participant needed to be excluded from the experiment.

Scenarios and calculations

The scenario reflected an early part of a mechanical engineering task: the selection and specification of a solution principle (for an overview see Table 2). The aim for participants was to select a solution that met particular requirements (e.g., low costs and high output). The solutions were two machine components, a turnover wheel and a turnover belt. They could be specified regarding four properties (i.e., dimensions, material, surface, and sensors) by selecting among two versions (e.g., 5 vs. 7 cm for dimensions). These two versions differed in their performance on four requirements (i.e., effort, costs, output, physical features), which was indicated by numerical values. Thus, one version was better than the other for any individual requirement and one was better than the other when adding up the values across all four requirements. All properties and requirements were treated alike in the calculations (see below). Accordingly, participants could ignore their identities (e.g., whether a property was dimensions vs. material or whether a requirement was effort vs. costs) and simply add up the numbers.

Numerical values and thresholds. The selected solutions had to meet a set of requirements. That is, participants had to make sure the numerical values of their specified solution remained below (or above) a global threshold for each requirement (e.g., total costs should not exceed 220 units). The local thresholds for the property/requirement combinations had values of either 40, 50, 60, or 70 units, which were counterbalanced across the four properties that had to be specified consecutively (see lower part of Table 2). Ac-

Table 2. Overview of the scenario. Each solution had four properties, each property had two versions, and the thresholds of four requirements had to be met during each step of solution specification.

	Property 1: Dimensions	Property 2: Material	Property 3: Surface	Property 4: Sensors
Solution principle: Turnover wheel				
Version 1	5 cm	Steel	Coated	Without
Version 2	7 cm	Aluminium	Non-coated	With
Solution principle: Turnover belt				
Version 1	13 cm	Rubber	Grooves	Without
Version 2	17 cm	Fabric	No grooves	With
Requirements				
Effort	< 70	< 40	< 60	< 50
Costs	< 40	< 70	< 50	< 60
Output	> 50	> 60	> 40	> 70
Physical features	> 60	> 50	> 70	> 40

cordingly, summed over all four properties, the global threshold for each requirement was 220 units. In each specification step, participants should aim to choose property versions with values lower than the local thresholds for effort and costs, and higher for output and physical features. The actual values of the property versions were random numbers with a distance to the threshold of one to ten points. For instance, if costs had to be lower than a local threshold of 70 units, the costs for a version meeting this requirement were a random number between 60 and 69 units.

Solution feasibility. The feasibility of Adapt and Exchange solutions varied between five types of trials (see Table 1). For Adapt, solution feasibility was defined by whether it was possible to meet the requirement thresholds. Adapt could either be non-problematic, locally problematic, or globally problematic. (1) Non-problematic (A+) meant that all eight values (i.e., two versions of four properties) met the local thresholds. (2) Locally problematic (A(–)) meant that for one property one local threshold was violated by both versions (e.g., for dimensions the required costs of < 70 units were exceeded by both the 5 and 7 cm version). Threshold violations ranged from 11 to 19 units. However, this did not lead to a global problem, as it was compensated by the remaining properties. (3) Globally problematic (A–) meant that in addition to a local problem, the total achieved value on one requirement did not meet the acceptable global threshold of 220 units at the end of the property specification, no matter which versions were chosen during the trial. The total achieved values were calculated by adding the values of the four chosen versions in the four properties. The global threshold of 220 units was violated by one to three units at least, if participants had chosen optimally. Local problems led to global problems in 50% of the trials, whereas all trials with a global problem also had a local problem.

Contrary to Adapt, Exchange always met the local and global requirement thresholds. Instead, its feasibility was defined by whether the deadline for delivering the machine was shorter or longer than the time needed to construct the new component. Both the delivery deadline and the needed time were presented as numbers of days. (1) No problem (E+) meant that more days were left until the delivery deadline than days needed for construction, whereas (2) a scheduling problem (E–) meant that fewer days were left. The time left until the deadline was a random value between 21 and 30 days. The time needed for construction was 5 to 9 days shorter than this deadline if Exchange had no problem, and 5 to 9 days longer if Exchange had a scheduling problem.

All combinations of Adapt and Exchange feasibility were presented in the experiment, except for a global problem combined with a scheduling problem (A–E–), for which there is no viable solution.

Solution with higher point score. An overall point score was obtained for Adapt and Exchange, respectively. The trials differed in terms of which solution reached a higher point score when always choosing optimally (i.e., choosing the versions further away from the thresholds in the desired direction). This point score was created by adding the differences between each total requirement value (i.e., across all four properties) and its respective threshold. For instance, when the total requirement values were 191 for effort, 195 for costs, 236 for output, and 240 for physical features, the point score was the sum of their differences from 220, which is 93. The achievable point scores differed between Adapt and Exchange in a range of 7 to 32. Importantly, which solution reached a higher point score was independent of solution feasibility. For instance, even when Adapt was globally problematic, it could still score higher than Exchange if its violation on one requirement was compensated by the others. This enables a factorial combination of solution feasibility and solution with higher point score.

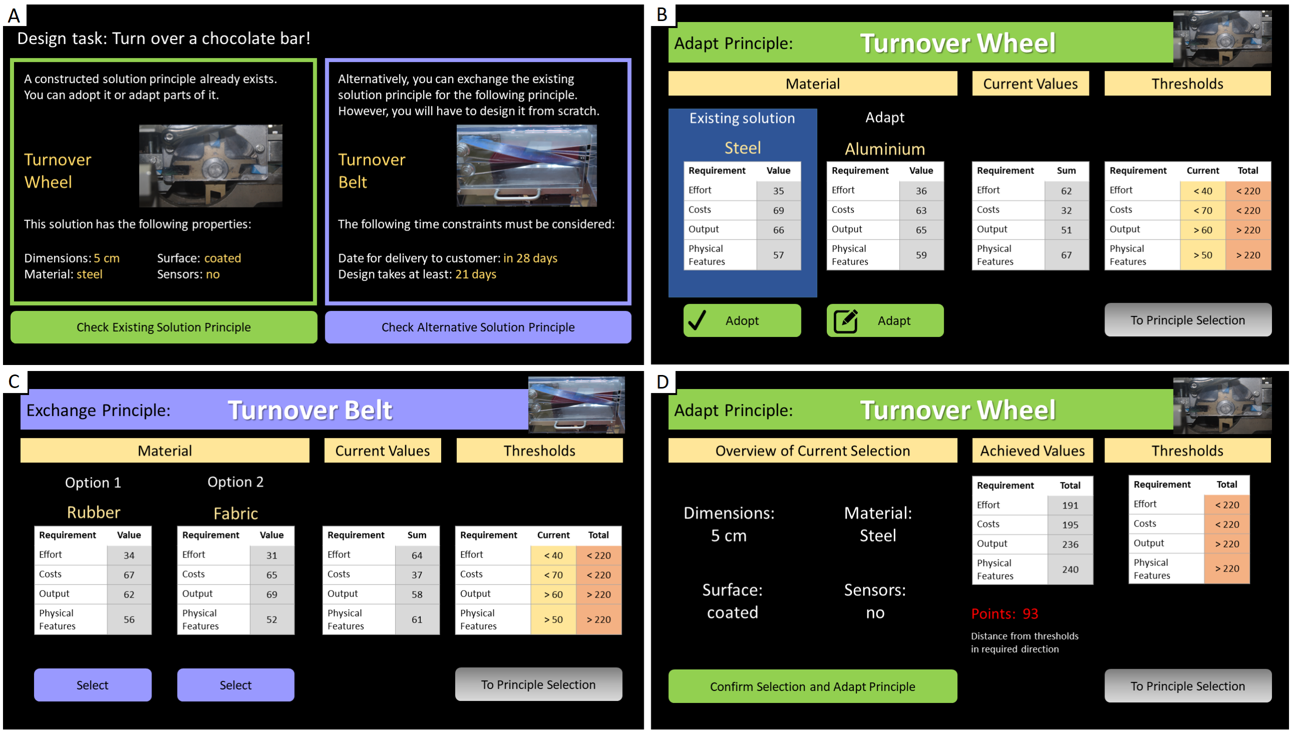

Figure 2. Procedure of a trial. Participants first selected a solution principle to check, then specified its four properties by choosing between two versions, and finally confirmed the specified solution. During each step, they could return to the principle selection and check the other solution. Adapt could either meet or not meet the local and global requirement thresholds, while Exchange always met them but could either meet or not meet a delivery deadline. P = property, V = version, R = requirement.

Screens

Stimuli were shown with a resolution of 1920 × 1080 pixels. All stimuli presented text, pictures, and interaction elements on a black background and with consistent colour coding (i.e., green for Adapt, purple for Exchange). All text was presented in German. Example stimuli are shown in Figure 2. There were three types of screens: a principle selection screen as well as four choice screens and one summary screen for each solution principle.

Principle selection screen. The principle selection screen (see Figure 2A) presented the task, two boxes for the solutions, and two buttons to check these solutions. The task shown at the top of the screen specified the intended machine function (i.e., "Turn over a chocolate bar!"). The two boxes always put Adapt on the left-hand side and Exchange on the right-hand side. They contained the respective component's name, description, picture, and additional information about it. The Adapt box stated that a solution already existed (e.g., turnover wheel) and that participants could adopt it as it is or partly adapt it. In addition to the solution's name and picture, its current properties were listed (e.g., dimensions: 5cm). The Exchange box stated that alternatively, another solution principle could be applied, but that it would have to be designed from scratch. In addition to its name and picture, a delivery deadline and the minimum days needed for construction were shown. Below each box, a button allowed participants to check the two solutions.

Choice screens. The choice screens (see Figure 2B and C) provided information about each property of the respective solution. The upper part of the screen presented the solution (e.g., Adapt) as well as the component's name and picture (e.g., turnover wheel). The middle part specified the current properties (e.g., dimensions), values, and thresholds. For each property, two versions were available (e.g., 5 and 7 cm). Adapt and Exchange slightly differed in how these versions were presented. For Adapt, version 1, which corresponded to the current implementation, was labelled "existing solution" and highlighted by a blue box, while version 2 was labelled "Adapt" and presented without highlighting. For Exchange, the two versions were labelled "option 1" and "option 2", respectively, and none was highlighted. For each version, a table listed its values on four requirements (i.e., effort, costs, output, physical features). The current values provided the sum for each requirement based on the previous choices. The thresholds indicated the maximum value (for effort and cost) or minimum value (for output and physical features) that needed to be achieved. These thresholds were provided for both the current trial and the total (i.e., sum over all four properties). As the current thresholds *should* be met, they were highlighted in yellow, and as the global thresholds *had to* be met, they were highlighted in red. The lower part of the screen provided buttons for the available actions. Below each version, a button allowed participants to select it. For Adapt, the buttons were labelled "Adopt" for the current version 1 and "Adapt" for the adapted version 2 (note that in German these two terms are not similar). For Exchange, both buttons were labelled “Select”. Finally, a “To Principle Selection” button allowed participants to return to the principle selection screen.

Summary screen. For each solution principle, a screen summarised the specifications of the four properties that had been selected on the previous choice screens (see Figure 2D). The upper part of the summary screen was identical to the choice screens, naming and visualising the solution. The middle part provided a list of the selected property versions (e.g., dimensions: 5 cm, material: steel, surface: coated, sensors: no), the sum of the achieved values for each requirement, and the global thresholds. Moreover, it provided a total point score indicating the summed deviations from the thresholds in the desired direction. The lower part of the screen provided a button to confirm the current solution and a button to return to the principle selection screen.

Procedure

First, participants watched the instruction video and completed the knowledge test. The experiment consisted of one practice trial and thirty experimental trials. The practice trial was an A+E+ trial, meaning that both solutions were feasible without any problems. There were three blocks of ten experimental trials. These ten trials corresponded to all combinations of the two within-participants factors *solution feasibility* (A–E+, A(–)E+, A(–)E–, A+E+, A+E–) and *solution with higher point score* (Adapt, Exchange). The order of trials in a block was randomised for each participant individually, and the order of blocks was counterbalanced across participants. It also was counterbalanced which component (i.e., turnover wheel, turnover belt) served as the current (Adapt) or alternative (Exchange) solution.

Participants could already infer the feasibility of Exchange on the principle selection screen by comparing the available time to the delivery deadline. To infer the feasibility of Adapt, they had to go through all four choice screens to check the four properties (i.e., calculating whether the solution met the requirement thresholds). In A– and A(–) trials, there was one property (e.g., dimensions) for which neither of the two versions (e.g., 5 and 7 cm) met one of the requirements (e.g., both were too costly). The problematic property and requirement as well as the requirement violating a global threshold were selected pseudo-randomly, with the constraint of being evenly distributed across requirements and properties.

A schematic overview of the trial procedure is provided in Figure 3. Each trial started with the principle selection screen on which participants had to select whether they wanted to check and specify the current solution (Adapt) or the alternative solution (Exchange). For checking Adapt, participants had to click the left green button (“Check Existing Solution Principle”) and for checking Exchange, they had to click the right purple button (“Check Alternative Solution Principle”). Clicking one of these buttons led them to the first choice screen. As the procedure of checking and specifying a solution was identical for both solution principles, the following paragraph will only describe this procedure for Adapt.

On the four choice screens, participants selected between two versions for each of the four properties. In the first step, they had to specify the component’s dimensions by either adopting the current dimensions (5 cm) or adapting them (7 cm). To this end, they had to compare these two versions on four requirements (i.e., effort, cost, output, and physical features). For instance, if the acceptable cost threshold is 70 units, you might prefer version 2 which costs 63 units to version 1 which costs 69 units. After completing

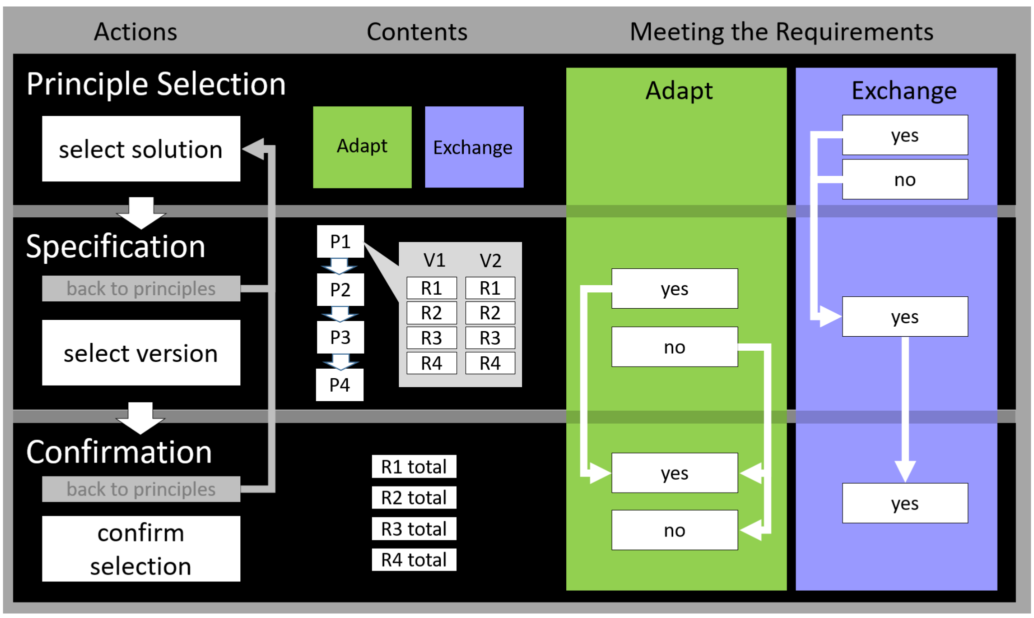

Figure 3. Stimulus material. (A) Principle selection screen. (B) Choice screen Adapt. (C) Choice screen Exchange. (D) Summary screen Adapt. In the experiment, all text was presented in German.

this comparison, participants could either choose the current version by clicking the left button ("Adopt") or the adapted version by clicking the right button ("Adapt"). Choosing a version brought participants to the second, third, and fourth choice screen, where they performed the same procedure for the component's material, surface, and sensors, respectively. At any point, they could abort their checking procedure and return to the principle selection screen. After having specified all four properties, the summary screen appeared (see Figure 2D). Participants could compare their performance on each requirement to the global thresholds, and view their overall point score. By clicking one of two buttons, they could either confirm this solution and end the trial ("Confirm Selection and Adapt Principle") or return to the principle selection screen ("To Principle Selection"). Taken together, an experimental session took about one and a half hours.

Data analysis

We analyzed participants' choices and their underlying information acquisition behaviour. Choices were quantified by calculating the percentage of trials in which participants chose Exchange. We computed a 5 (*solution feasibility: A–E+, A(–)E+, A(–)E–, A+E+, A+E–*) × 2 (*solution with higher point score: Adapt, Exchange*) repeated measures ANOVA.

Information acquisition behaviour was operationalised as the percentage of trials in which participants checked the Exchange solution. Thus, an Exchange checking rate of 100% means that a participant went through the four choice screens of Exchange in every single trial. Instances of checking a solution were excluded if participants aborted their checking procedure (i.e., not checking all four properties), which led to an exclusion of 6.1% of the total checks. To analyze information acquisition, we computed a one-way 5 (*solution feasibility: A–E+, A(–)E+, A(–)E–, A+E+, A+E–*) repeated measures ANOVA. For exploratory purposes, we performed the same ANOVA for the percentages of checking Adapt.

For all ANOVAs, if sphericity was violated, the Greenhouse-Geisser correction was applied and the degrees of freedom were adjusted accordingly. To determine statistical significance, an alpha level of $p < .05$ was used, and all pairwise comparisons were performed with Bonferroni correction.

In an exploratory analysis, we examined participants' individual approaches of information acquisition. Specifically, we looked at the order in which they checked the two solutions (i.e., which solution is checked first, and whether solutions are checked repeatedly).

Results

Choosing Exchange

Overall, participants chose Exchange in 30.9% of the trials. The ANOVA revealed significant main effects of solution feasibility, $F(2.8, 66.6) = 52.42$, $p < .001$, $\eta^2 = .69$, and solution with higher point score, $F(1, 24) = 20.2$, $p < .001$, $\eta^2 = .46$, as well as an interaction that just reached significance, $F(3.0, 70.8) = 2.81$, $p = .046$, $\eta^2 = .11$ (see Figure 4A and Table 3). The main effect of solution feasibility indicated that the rate of choosing Exchange depended on the presence of problems in both solutions. When Exchange was feasible, the results were in line with the weak satisficing strategy (*H3*): Exchange was mostly chosen when Adapt was globally problematic (A–E+), less when Adapt was only locally problematic (A(–)E+), and even less when Adapt was non-problematic (A+E+) (72.0% vs. 44.0% vs. 26.0%), all *p*s < .03. The effect sizes for these pairwise comparisons were medium to large, ranging from $d_z = .67$ to 1.77. Conversely, the data did not support the strong satisficing strategy (*H4*): When Adapt was non-problematic, Exchange was chosen more often when it was feasible (A+E+) than when it was not (A+E–) (26.0% vs. 4.7%), $p = .03$. This effect was large as well, $d_z = .87$. The main effect of solution with higher point score indicated that Exchange was chosen more often when it scored higher than Adapt (40.5% vs. 21.3%). Although the same basic choice pattern was observed regardless of which solution scored higher, the significant interaction can be attributed to stronger effects of solution feasibility when Exchange did. However, the difference between A+E+ and A+E– did not reach significance for either type of solution with higher point score alone, neither for Adapt, $p = .18$, nor for Exchange, $p = .054$. Thus, when Adapt was non-problematic, Exchange choices were rare overall, and the feasibility of Exchange did not make a significant difference. Admittedly though, with regard to our hypothesis that participants adopt a strong satisficing strategy (*H4*), this is weak evidence at best. Only because a descriptive difference misses significance, this does not warrant inferring that it does not exist. In fact, despite not being significant, the latter two pairwise comparisons had effect sizes that were medium when Adapt reached the higher point score, $d_z = .56$, and even large when Exchange did, $d_z = .84$.

Checking Exchange

Overall, Exchange was checked less than half as often as Adapt (41.7% vs. 87.7% of all trials). However, these Exchange checking rates strongly depended on solution feasibility (see Figure 4B and Table 3). There was a significant effect of solution feasibility, $F = (4, 96) = 55.79$, $p < .001$, $\eta^2 = .70$. The pattern of results mirrored the one observed in the analysis of choice behaviour. In line with the weak satisficing strategy (*H3*), Adapt feasibility modulated the rate of Exchange checking, given that Exchange was feasible. That is, Exchange was checked most often when Adapt was globally problematic (A–E+), less when Adapt was only locally problematic (A(–)E+), and even less when Adapt was non-problematic (A+E+) (88.0% vs. 58.0% vs. 37.3%), all *p*s < .03. The ef-

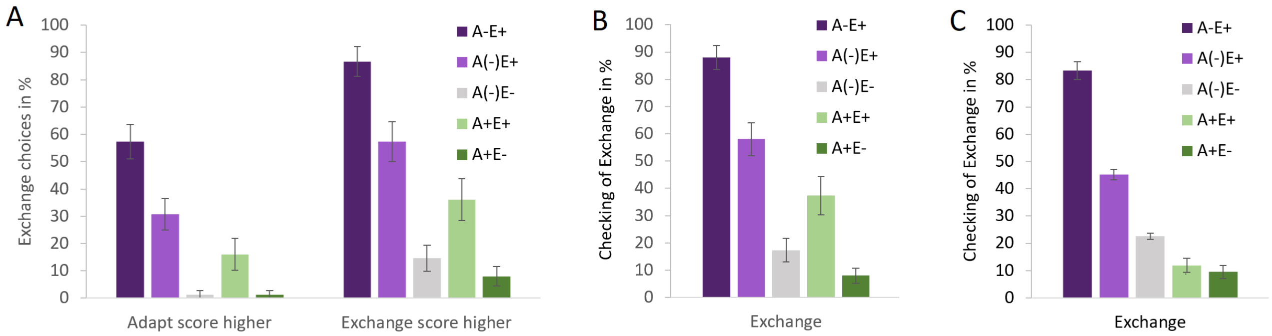

Figure 4. Mean rates of choices and information acquisition (in % of trials), depending on solution feasibility. (A) Choices of Exchange depending on which solution reached the higher point score. (B) Checking Exchange for all participants. (C) Checking of Exchange for the subsample of participants ($n = 14$) who started by checking Adapt in at least 80% of the trials. Error bars represent standard errors of the mean.

fect sizes for these pairwise comparisons were medium to large, ranging from $d_z = .63$ to 1.65. However, contrary to the hypothesis that participants adopt a strong satisficing strategy (*H4*), when Adapt was non-problematic, Exchange was checked more often when it was feasible (A+E+) than when it was not (A+E–) (37.3% vs. 8.0%), $p = .006$. This was a large effect, $d_z = .96$.

Exploratory analyses

The exploratory analysis of checking Adapt revealed that when Exchange was not feasible, Adapt was almost always checked (98.7%). More surprisingly, when Exchange was feasible, Adapt was only checked in 80.5% of the trials. Thus, there was a large share of trials in which participants immediately went for the alternative solution. To better understand participants' individual approaches of information acquisition, we plotted which solution they checked at what time of the trial (see Figure 5). An inspection of this figure corroborates the conclusion drawn from the analysis of Adapt checking rates: Contrary to our assumptions, not all participants started a trial by checking Adapt. In fact, only seven participants always started with Adapt (top row of Figure 5). Other participants started by checking Exchange more or less often. For instance, participants 20-25 (bottom row of Figure 5) preferably started with Exchange when Exchange was feasible (E+). It needs to be noted that both versions of the satisficing strategy (*H3* and *H4*) rested on the assumption that people start by checking Adapt, because this is a necessary condition for knowing whether Adapt is good enough. Therefore, our lack of support for the strong satisficing strategy (*H4*) might be attributable to the fact that some participants did not fulfil this basic condition.

To test this possibility, we repeated the analysis of Exchange checking rates for only those participants who usually fulfilled the necessary condition for satisficing, starting by checking Adapt in more than 80% of the trials (14 participants, 56% of the sample). There was a significant effect of solution feasibility, $F(4,52) = 42.278$, $p < .001$, $_{\mathrm{p}}^{2} = .765$ (see Figure 4C). In line with the strong satisficing strategy, when Adapt was non-problematic, the frequency of checking Exchange did not differ between trials in which Exchange was feasible (A+E+) or not feasible (A+E–) (11.9 and 9.5%), $p > .9$, and the effect size of this pairwise comparison did not even meet the criteria for a small effect, $d_z = .153$.

Arguably, the cut-off of 80% trials that started by checking Adapt is quite arbitrary. Therefore, we repeated the analysis with different cut-offs to test the stability of the strong satisficing strategy. We used cut-offs of 70% (including 18 participants, 72%), 50% (including 21 participants, 84%) and a median split of the sample (including 13 participants, 52%). The strong satisficing strategy was supported consistently:

Table 3. Mean rates of choices and information acquisition (in% of trials) as well as their standard deviations (in parentheses) for choice and information acquisition.

	Solution feasibility				
	A–E+	A(–)E+	A(–)E–	A+E+	A+E–
Choice (solution with higher point score)					
Adapt	57.3 (31.2)	30.7 (28.7)	1.3 (6.7)	16.0 (29.1)	1.3 (6.7)
Exchange	86.7 (27.2)	57.3 (36.7)	14.7 (23.7)	36.0 (38.4)	8.0 (17.4)
Information acquisition (checking of solution)					
Adapt	80.7 (22.4)	80.7 (24.9)	98.7 (27.6)	80.0 (4.6)	98.7 (6.7)
Exchange	88.0 (22.3)	58.0 (30.5)	17.3 (21.2)	37.3 (35.1)	8.0 (13.7)

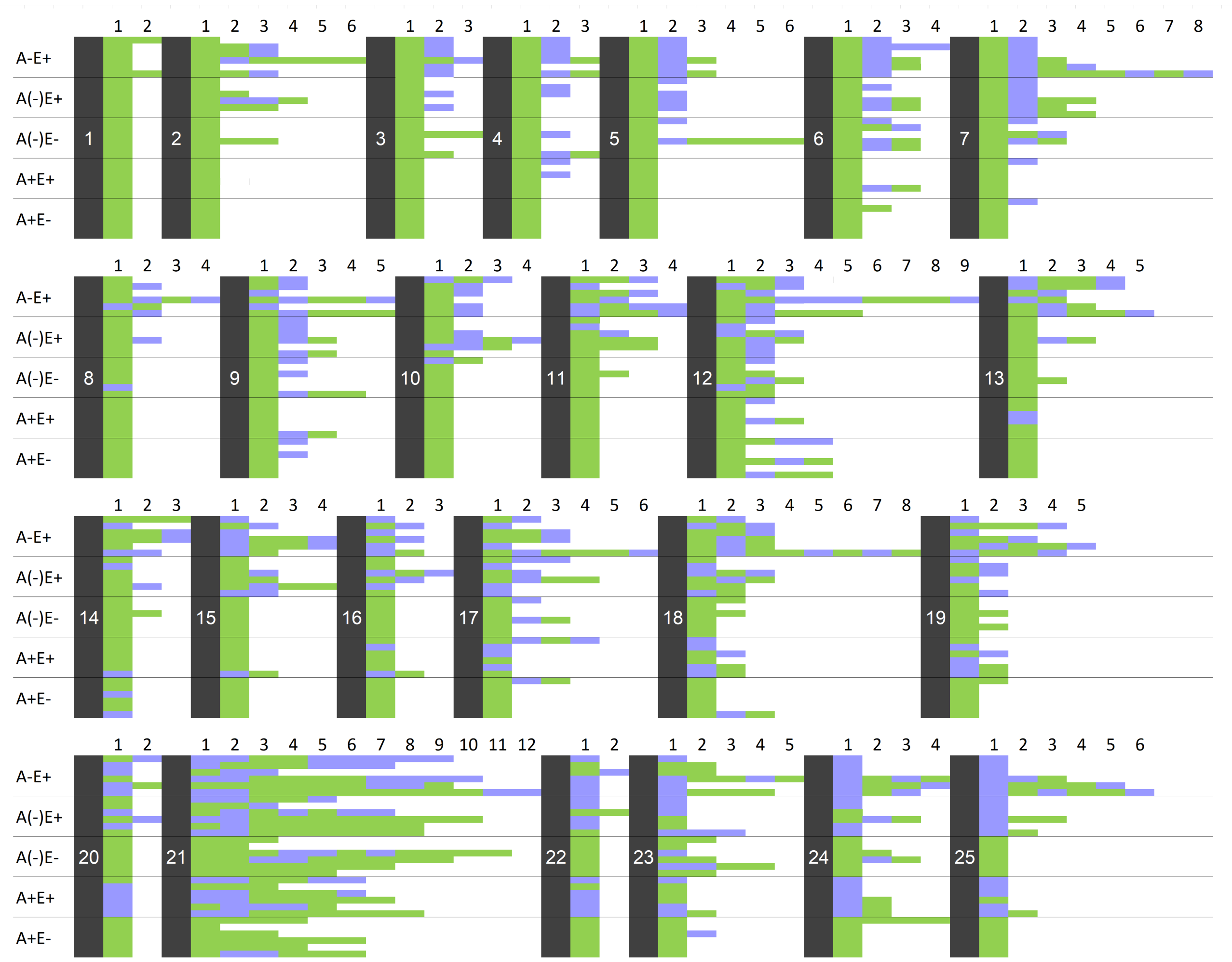

Figure 5. Individual checking behaviour for all participants and trials. Each black bar represents one participant (sorted by the frequency of checking Adapt first) and the green and purple cells indicate instances of checking Adapt and Exchange, respectively (only complete checks of all four properties are included). The vertical direction represents the 30 trials, sorted by solution feasibility. The horizontal direction represents at what time a solution was checked (e.g., first, second, third). When only green cells are attached to the right of a black bar (i.e., participants 1–7), this means that Adapt was always checked first. When chains of cells extend far to the right, it means that a participant performed several rounds of checking, either by checking the same solution repeatedly (e.g., participant 21, fourth trial of A+E–) or by frequently switching between Adapt and Exchange (e.g., participant 7, last trial of A–E+). The last solution checked in each row is the one ultimately chosen.

In all these analyses, the difference between A+E+ and A+E– failed to reach significance, all $ps > .1$, although obviously the effect sizes grew larger as more participants of the original sample were re-included, ranging from $d_z = .252$ to $d_z = .547$. These results indicate that the majority of participants acted according to the strong satisficing strategy, except for those who cannot possibly know whether Adapt is good enough as they did not check it.

That said, an inspection of Figure 5 also reveals that participants' information acquisition approaches are diverse and cannot be condensed into one general strategy. Instead, participants show a wide variety of different behavioural patterns. At first glance, it seems compelling to translate them into a set of rules and classify participants according to the rules they adhere to. In some cases, this seems quite possible. For instance, one rule could be "first check Adapt, stop if A+, definitely check Exchange if A–, usually check Exchange if A(–)", which fits reasonably well for P3-P7. Another rule could be "first check Exchange if E+, otherwise check Adapt", which might partly explain the actions of P22, P24, and P25. However, Figure 5 also reveals that aside from a few exceptions, such simple rules are insufficient to describe participants' information acquisition behaviour. They might highlight some individual tendencies but cannot explain why the majority of participants adopted different strategies within one and the same trial type. This suggests that the feasibility of solutions (i.e., trial types) per se cannot account for participants' information acquisition behaviour. We will return to this issue in the Discussion.

Discussion

The balance between stability and flexibility is at the heart of Adapt/Exchange decisions (Müller & Urbas, 2017). When faced with a problem, should decision-makers stick with a solution that was successful in the past or should they try out a new one? To make this choice, decision-makers could carefully evaluate both solutions and then choose the superior one. However, when balancing stability and flexibility in real life, there is a trade-off between thoroughness and efficiency (Hollnagel, 2009). This trade-off is partly dependent on the benefits and costs of acquiring information (Fiedler & McCaughey, 2023; McCaughey et al., 2023). Is it even worth checking alternative solutions when the current solution already is good enough? The present study examined under what conditions people engage in this extra effort.

Overview of the study and findings

Participants performed a simplified mechanical engineering task in which they could either adapt the physical properties of an existing machine component or exchange this component for a new one. A cognitively demanding multi-step procedure allowed them to check how the solutions fulfilled several requirements. Requirement fulfilment was manipulated between trials to assess under what conditions participants thoroughly acquire information about both solutions. As expected, our results clearly refuted the hypothesis we had considered unlikely to begin with, namely that participants do not check the alternative solution (*H1*). Moreover, they also refuted the more plausible hypothesis that they check it consistently (*H2*): Even when Exchange was feasible, it still was only checked in 61.1% of the trials. Obviously, participants did not attempt to maximise accuracy at any cost. Did they satisfice instead? While our results supported the weak satisficing strategy (*H3*), they were not in line with the strong satisficing strategy (*H4*): Exchange checking rates decreased as Adapt became more feasible, but even when Adapt did not show any problems at all, Exchange checking rates still exceeded the lower baseline of non-feasible Exchange. However, exploratory analyses of individual participants' information acquisition approaches revealed a crucial dependency: whether participants actually started by checking Adapt, which is the only way of knowing whether it is good enough. Strong satisficing was evident if and only if its necessary condition was met.

This additional analysis revealed that we had based our hypotheses on an unwarranted assumption, presupposing that participants generally start with the default solution. In reality, however, participants adopted a wide variety of approaches. Upon closer consideration, starting with Exchange is quite reasonable. In this way, you only have to go through the cognitively demanding Adapt procedure once, instead of a first time before checking Exchange and then a second time afterward. However, sometimes participants also started by checking Exchange and then immediately chose it, without checking Adapt at all (in fact, 68% of the participants did this at least once). Seemingly, satisficing can go both ways – high information acquisition costs might generally discourage people from checking another solution after finding one that performs reasonably well. The following sections will discuss our findings in the light of previous research, highlight limitations of the study, and suggest directions for future work.

Why did participants not check both solutions consistently?

An alternative hypothesis that we contrasted with satisficing was that participants consistently check both solutions (*H2*). This hypothesis was based on the strong accuracy bias observed in various decision contexts (Fiedler & McCaughey, 2023; Fiedler et al., 2021; Manzey et al., 2014; Müller et al., 2020; Müller et al., 2019). However, there was no evidence for consistent (over-)checking, or only in the few participants excluded from the exploratory analysis who routinely started by checking Exchange. We can conceive of two potential explanations, which are not mutually exclusive.

First, the *cognitive demands of checking* a solution were considerably higher than in previous studies. Participants had to perform mental arithmetic in a multi-step procedure and keep track of the results throughout the trial. When checking another solution, they had to memorise the point score of the previous one and later compare both scores. Conversely, the checking procedures in previous studies typically required sequences of manual actions, comparisons of parameter readings to nominal values, and passive waiting. Thus, information acquisition was time-consuming and tedious, but not as cognitively demanding as in our Adapt/Exchange scenario. In the future, it will be interesting to systematically investigate whether and how the checking of alternative solutions varies with the type of information acquisition costs.

A second reason for inconsistent Exchange checking might be the *absence of clear performance criteria*, inviting a large interindividual variation in information acquisition approaches and checking effort. In previous studies, failing to check could result in wrong diagnoses (Müller et al., 2020; Müller et al., 2019) or missed alarms (Manzey et al., 2014). In the present study, the only incorrect choice was selecting a non-feasible solution, but other than that, participants were free to set their own standards. Higher checking effort predicted higher performance with regard to the numerical requirements (i.e., lower deviations from the point score optimum), $r = -.66$, $p < .001$. However, it was not mandatory for participants to prioritize this criterion. Some of them did and thus checked both solutions. For instance, at first glance it seems puzzling that Exchange still was checked in 8% of the trials when Adapt was non-problematic and

When calculating this correlation, one participant was excluded as an extreme outlier (participant 21 in Figure 5). This participant performed 6.2 checks per trial on average, while the averages for all other participants ranged from 1.1 to 2.4 checks. When including the participant, the correlation missed significance, $r = -.39$, $p = .056$.

Exchange was impossible (i.e., A+E–). However, one participant remarked after the experiment that the Exchange deadline had not played much of a role for her, because deadlines can be moved if this means that the customer will get a much better machine. For her, optimizing the point score was more important than staying within the specified time limits. Conversely, other participants indicated that they had considered the additional construction effort of Exchange unjustified in general, and therefore avoided this solution whenever possible, eliminating the need to check its performance.

This subjectivity in defining what makes a good solution stems from a key feature of Adapt/Exchange decisions: Their cost metrics are incommensurable (cf. Müller, 2024). For instance, does a point score benefit of 15 units justify 23 extra days of constructing the component? Although this renders decision-making less straightforward, it is a common feature of the real world. In many situations, there are no numbers at all that can be used to specify a solution's performance, or only for some requirements but not others. Thus, people have to (1) integrate incommensurable pieces of quantitative information and (2) integrate quantitative with qualitative information. This is in line with a key characteristic of complex problem solving, namely that there are multiple, ill-defined goals that have to be specified and weighted by problem solvers (Dörner & Funke, 2017; Ren et al., 2019). Yet, these challenges have largely been ignored in previous decision-making research (but see Müller & Blunk, 2024). It will remain an exciting prospect for future research to investigate how people balance qualitatively different costs and benefits.

What can we learn about decision-making in Adapt/Exchange scenarios?

Our results corroborate the speculative conclusion from previous Adapt/Exchange studies that participants might satisfice (Müller, 2024; Müller & Urbas, 2020). Given the consistent results across different Adapt/Exchange scenarios, a critical question is what insights they provide. Do they teach us anything new, beyond what is already known from traditional decision-making research? One novel aspect is that we found evidence for satisficing with only two options, while traditionally, satisficing has been observed when the number of options was large or unknown (Simon, 1956; Todd et al., 2012; Todd & Miller, 1999). As discussed above, we largely attribute this finding to the high information acquisition costs. In line with this, other studies found that people rely on heuristics and shortcuts more when information search and integration is hard (Glöckner & Betsch, 2008; Söllner et al., 2013) and that they consider fewer options when evaluation costs are high (Hauser & Wernerfelt, 1990).

One might argue that such dependence on information costs is trivial. However, this raises serious concerns about the generalisability of psychological findings. In most decision-making studies, all information was readily available or could be obtained with minimal effort. Conversely, in real-world decisions, people actively collect information, for instance by searching the internet or performing series of measurements. Is it warranted to isolate the "core processes" of decision-making from the tedious processes of getting to know one's options? The reductive approach of psychological research sure has its benefits. However, we argue for a complementary, more ecologically inspired perspective. Given that people show a tendency to economise during complex problem solving (Schoppek, 2023), realistic information acquisition costs do not seem to favour a flexible consideration of new solutions.

That said, the propensity to adapt or exchange will also depend on the work domain. Initial evidence in the context of expert fault diagnosis (Schmidt & Müller, 2023) suggests that malfunctioning components are more often adapted for packaging machines and more often exchanged for cars. Such differences are deeply rooted in the characteristics of the respective socio-technical system, instead of merely depending on the human problem solver.

Limitations of the present study

Obviously, the standard limitations common to most psychological studies apply to the present study as well, such as the sample size not being very large ($N = 25$). Still, a post hoc power analysis revealed that the achieved power for the effect of solution feasibility was high ($1 - \beta > 0.99$). This is not surprising, given the large effect size ($\eta^2 = .70$) due to considerable differences between some of the solution feasibility conditions. Therefore, we repeated the analysis of achieved power for the most relevant pairwise comparison (i.e., A+E+ vs. A+E–). For the entire sample, it was $1 - \beta > 0.99$ (given an effect size of $d_z = .96$), whereas for the subsample that usually started with Adapt ($n = 14$), it was $1 - \beta = .08$ (given an effect size of $d_z = .15$). Thus, the hypothesis that participants adopt a strong satisficing strategy (*H4*) could be refuted with high certainty for the entire sample but not for those participants who fulfilled the necessary conditions for satisficing (note that the overall power for the effect of solution feasibility in this subsample still was $1 - \beta > 0.99$). Taken together, this suggests that although the sample size could be larger, this did not have a major impact on the results.

More interesting are the content-based limitations specific to the present study. The study rests on a tradition of engineering psychology that starts from a real-world problem, extracts its structure, and transfers it to a simplified lab experiment. This requires a delicate balance between peeling off enough confounding factors to gain sufficient experimental control, but not removing the essence of the problem of interest. This search for balance necessarily results in limitations of internal and external validity.

Perhaps the main limitation of internal validity is the *number concept* underlying our requirement values and time delays. While our hypotheses were only based on solution feasibility (e.g., A+E–), the absolute values varied between trials (e.g., Adapt reaching 93 vs. 78 points). Participants most likely did not ignore that. Some might even have decided whether Adapt is "good enough" based on its point score compared to previous trials or based on its performance on their favourite requirement. Accordingly, different participants probably set different subjective criteria for satisficing. A related limitation is that the *point scores differed between participants* as they depended on their choices within a trial. Accordingly, in one and the same trial, one participant might have concluded that it is not worthwhile to check Exchange, while another one might have concluded that it is crucial. Future studies could address these limitations by moving the paradigm further into the direction of a closely controlled lab experiment, for instance by explicitly defining the importance of each requirement, restraining participants' interpretation of numerical values, or instructing particular strategies. However, given that such explicit constraints and criteria are rare in most problem solving contexts, this comes at the cost of further increasing the gap between psychological research and the real world.

The present study also had its share of limitations regrading external validity. One of them is the implementation as a *simplistic lab experiment performed by non-experts*. This limitation has several aspects. For instance, our participants could base their decisions on data and numbers, which were available for almost every relevant aspect of the decision, whereas in reality, this almost never is the case. Little additional, non-specified information was relevant, and neither expert knowledge nor the decision history beyond a single trial played any role at all. These limitations have several specific consequences. One of them is that for our participants, the Adapt solutions were just as new as the Exchange solutions and all differences were merely based on instruction. Also, our participants presumably did not represent the solutions in terms of their functional principles and thus did not conceive of their choices as movements in an abstraction hierarchy. Finally, they did not actually have to expend the additional Exchange effort of spending about a month constructing a new machine component. All these factors are likely to have affected their choices. To address this limitation, future research could complement lab studies with observational studies or quasi experiments to investigate how experts from various domains tackle Adapt/Exchange decisions in their respective area of expertise. This would also be conducive to extracting generalisable principles of Adapt/Exchange decisions, rather than rooting them in just one specific application area.

A second limitation of external validity is that the *integration of goal criteria was far too simple*. In reality, Adapt/Exchange decisions require an integration of qualitatively different goals. In most cases, this cannot be done by integrating numerical information. But even if data and numbers were available for every relevant aspect, how should they be integrated? For instance, does a 5% increase in output justify a 10% increase in costs? While our participants had to integrate different requirements, these requirements did not actually have meaning – participants could simply add up the numbers. This is in stark contrast to the complex, multi-factorial decision-making required in real life. To address this limitation, future studies could use Adapt/Exchange scenarios in which the goals and constraints are meaningful to participants, for instance because they concern their own lives. This can change people's decision-making and information processing strategies (Goldstein & Weber, 1995; Rettinger & Hastie, 2001). However, such studies should be complemented by knowledge elicitation techniques to make it transparent how participants integrate qualitatively different, conflicting goals.

A final limitation of external validity is the *role of short- versus long-term consequences*. In realistic engineering tasks, a designer's information acquisition costs right now presumably weigh less than a customer's hassles for the next 30 years after purchasing an inferior machine. Thus, one might conclude that in reality, people will always make the effort to check a reasonable alternative solution. However, it should be considered that in reality, checking also is much more demanding and time-consuming than in the present study. Moreover, uncertainty will be an issue, which we completely eliminated from our experiment. Thus, engineers also do not usually check all alternative solutions (Ball et al., 1994; Fricke, 1996; Ullman et al., 1988). This limitation could be addressed by conducting observational studies to track the decision-making processes of engineers in their everyday work.

Outlook for future research

We are only at the very beginning of understanding Adapt/Exchange decisions, and many questions remain to be answered. One of them is whether people know what *amount of information acquisition is optimal*. Our participants often refrained from checking Exchange – but is this a bad thing? Not necessarily, as cross-checking automated systems draws resources from other tasks and thus can even be harmful (Manzey et al., 2014; Moray & Inagaki, 2000). Moreover, deciding on the basis of very few observations can be optimal when information acquisition is costly (Vul et al., 2014). However, people seem to be quite insensitive to the relation between the gains and costs of information acquisition (McCaughey et al., 2023). To examine this sensitivity for Adapt/Exchange decisions, it is necessary to systematically manipulate the costs of checking alternative solutions and the benefits these solutions can achieve.

Along the same lines, it should be investigated *how thoroughly people acquire information* about a solution principle, instead of just whether. If plenty of information was available about each solution, when would people stop sampling? While this has been studied in other decision contexts (Gonzalez & Aggarwal, 2023;

Prager et al., 2023), to date it is unclear when people truncate their process of investigating an alternative solution and decide that the status quo is preferable. Conversely, it could also be investigated how long people try to adapt if the checking procedure reveals difficulties. Significant costs down the line can be expected when adaptations require more and more compromises. However, given that people tend to perseverate and adhere to the status quo (Betsch et al., 2002; Jachimowicz et al., 2019; Samuelson & Zeckhauser, 1988; Scherbaum et al., 2013), they might give up trying to adapt a current solution rather late. Yet, it is unclear which factors this depends on, such as the point in time when problems become obvious or the sunk costs that have already gone into an adaptation.

From an application perspective, future research should contemplate the design of *interventions to support Adapt/Exchange decisions*. Decision support systems could counteract design fixation and support creative problem solving (Althuizen & Wierenga, 2014; Youmans & Arciszewski, 2014). Moreover, they could facilitate the comparison of solutions, supporting problem solvers in navigating the abstraction hierarchy (Bisantz & Vicente, 1994; Müller & Urbas, 2023). In this way, a situationally optimal balance between stability and flexibility could be achieved collaboratively by joint cognitive human-machine systems.

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