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Human error in complex problem solving and dynamic decision making: A taxonomy of 24 errors and a theory

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ABSTRACT

The current study extends existing research on human error by investigating human error in complex, dynamic, and uncertain microworlds. The main goal was to develop a taxonomy of errors for such situations. Several tasks with differing characteristics and demands on the problem solver were used: the simulation of a chocolate producing company (CHOCO FINE), the simulation of a tribe of semi-nomads in the Sahel zone (MORO), and the simulation of wildfires engaging fire-fighting units (WINFIRE). Observing participants and teams working on these simulations, we refer to specific cases and describe 24 errors related to the steps of human problem solving and dynamic decision making. A theory is then presented which attempts to explain the causes of these errors occurring in microworld contexts. Whereas most existing theories focus on cognitive explanations, the theory presented explains human error as a result of the interaction of emotions, motivations, and cognition. The current study not only extends the taxonomy and list of human errors, but especially addresses the lack of theoretical explanations in the literature on human error. The findings provide a starting point for further theory development and empirical testing and could be applied in training programs; hopefully contributing to sensitivity and awareness of the demands of complex, dynamic, and uncertain problems, and ultimately contributing to fewer human errors.

1. Introduction

Human error in various domains of life can lead to enormous financial costs, sometimes to ecological disasters, and, in the most dramatic cases, to loss of human life. Examples of both ecological disasters and loss of human life due to human error include the Chernobyl nuclear power plant disaster in 1986 and the BP oil spill in the Gulf of Mexico in April 2010.

Human error is quite frequent in various work environments. Survey results have shown that "70 per cent of aircraft accidents, as well as 80 per cent of shipping accidents, and at least 58 per cent of medical misadventures"– and this is a conservative estimate – can be attributed to human error (Hobbs, 2008, p. 9; Wiegman & Shappell, 2001). Up to 75% of all roadway crashes are due to human error (Stanton & Salmon, 2009). In the business world, about 50% of management decisions fail (Nutt, 2002), and 50% of wrong decisions could have been avoided (Carroll & Mui, 2008). Thus, the investigation of human errors and their causes is not only of theoretical but also of practical importance.

The main goal of the current research is to describe a list of errors shown in complex, dynamic, non-transparent simulated problem situations. Our approach is comparable to the one of an ethnographer who observes and describes certain phenomena and lists them. We also attempt to discuss and justify why specific behaviors can be considered errors and where these errors could come from referring to emotional, motivational, and cognitive processes. The current study does not describe which errors are more frequent in which kind of situations. The current study also does not describe which errors are shown more frequently by which group of participants, for example managers versus students. These could be questions for future research.

1.1. Taxonomies of human error

The research on human error and error taxonomies has been highly influenced by the seminal work of James Reason and Jens Rasmussen. We will discuss their work in detail because it has been adopted and used in many different fields (e.g., aviation; Wiegman & Shappell, 2003).

Rasmussen (1983) distinguished three levels of human behavior, with errors corresponding to each of the three levels. The first level is

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called *skill-based* behavior, which refers to highly practiced and automatic sensory-motor coordination, for example, bicycle riding. Errors can occur when coordinations are not adjusted to the changing characteristics of the environment, for example a slippery and declining road. The next level is called *rule-based* behavior and refers to a combination of rules and subroutines. Errors on this stage can be a result of misperceptions of situations, which leads to the application of the wrong rules or routines. For instance, a chess expert may misperceive a situation and take the risk of sacrificing a bishop, a routine that often led to success in the past, but in this case does not lead to the expected result. Whereas the skill-based level involves no conscious attention, rule-based behavior involves explicit know-how and explicit knowledge of the rules and routines. The third level, called *knowledge-based* behavior, is exhibited in novel situations when goals have to be formulated and no set of rules can be directly applied. Mental models of the situation and plans have to be developed. Errors on this level can be due to lack of knowledge or mental resources (see also Simon, 1972, bounded rationality). The current study will investigate errors at the knowledge-based level in more detail.

Reason (1990) based his analysis of human error on Rasmussen's levels. At the skill-based level, he distinguished errors due to inattention and overattention. An example of an error due to inattention is the action of taking off socks and shoes when it was intended to take off only the shoes. An example of an error due to overattention is playing a well-practiced piano piece incorrectly due to a decision to focus on playing a few notes very softly in pianissimo, thus interfering with the highly practiced routine.

At the rule-based level, Reason distinguished errors due to misapplication of good rules and application of bad rules. Misapplication of good rules means that rules that have been adequate in a particular situation are applied in a new situation. The new situation shares some properties with the previous situation, but some elements of the new situation are different – and this is the problem. An example of an error for good rules is related to the 9-dot problem. The task consists of connecting 9 dots with 4 straight, continuous lines. Most participants do not succeed because they do not think that they can go beyond the dots when drawing a line. Most likely their procedure is based on many years of schooling in math applying the rule "The shortest distance between two points is a straight line," or the laws of Gestalt to see a square when 9 dots are arranged in a specific way. This misapplication of good rules due to changes of situational characteristics has been described by Dörner (1996) as *methodismus*, a term Dörner borrowed from the military strategist von Clausewitz. In English perhaps better translated as methodical rigidity refers to the inflexible application of a learned sequence of action without considering changes in situational conditions (also called Einstellung effect; Luchins, 1942).

Bad rules result from difficulties with encoding the situation and action deficiencies. The task in physics of projecting the path of a ball coming out of a coiled tube could serve as an example related to encoding deficiencies. In a study, participants had to predict which direction the ball would take when leaving the tube. Forty percent of the students asked chose the curved trajectory answer, whereas the straight trajectory answer would be correct (McCloskey, 1983; cited in Reason, 1990).

Regarding knowledge-based errors, those related to problem solving in novel situations, Reason referred to several examples such as encystment (Dörner, 1980). Encystment means dealing with a small aspect of a complex problem situation in too much detail and not dealing with the main aspects of the problem.

Note that the preceding list of error types is not organized according to a theoretical framework. The current paper is an attempt to provide more examples of primarily knowledge-based errors occurring in complex, dynamic, and uncertain situations and to organize those according to the steps of problem-solving. The paper then attempts to explain why those errors happen and what the underlying causes are going beyond the explanations of Rasmussen and Reason, who primarily referred to lack of knowledge or mental resources (bounded rationality), difficulties with encoding the situation, and action deficiencies as causes for errors at this level.

1.2. Human error in real world contexts

One way to search for an error taxonomy is to analyze human error in disastrous real-life situations. Some researchers have taken historic political events and analyzed why they developed the way they developed focusing on the influential role of human error. Tuchman (1962), for example, described and analyzed the chain of events leading to World War I and to related disastrous military interventions. She demonstrated that the individual personalities of European political leaders, human errors in political and military considerations, and misunderstandings were the main causes for the outbreak of World War I. In analyzing the planning mistakes of the German military, her often repeated quote was, "Dead battles, like dead generals, hold the military mind in their dead grip, and Germans, no less than other peoples, prepare for the last war" (Tuchman, 1962, p. 38). The problem with planning is that most plan components of a new plan are taken from past plans. Thus, our plans are highly influenced by our past experiences, as Tuchman expressed so wisely.

Dörner and Güss (2011) analyzed Hitler's decision making during World War II leading to disastrous decisions such as those that resulted in the death of hundreds of thousands of German soldiers in Stalingrad. Top German military advisors advised Hitler to follow a different strategy, but Hitler stuck to his plan. Some of the causes discussed for Hitler's decision making errors were underestimation of the opponent and overestimation of one's own capabilities, the displacement of responsibility for failures on scapegoats such as Jews or Generalstab (general staff), methodical rigidity in decision making, and lack of self-reflection.

Other researchers have focused on the role of human error during technological disasters. Reason (1990) and Collier and Davies (1986), for example, described the role of human error during the Chernobyl disaster in April 1986. Although the Western nuclear industry blamed the poor design of the Russian reactor, analyses of the accident revealed human error as principal cause of the disaster. The nuclear power plant was supposed to be scaled down to 25% of its capacity to run some tests. Instead of letting the reactor automatically lower its capacity to about 25%, the operating technicians manually controlled the process and unintentionally lower the capacity to below 10%. Such a low capacity is, however, dangerous for a nuclear reactor because it becomes highly unstable. That is why a reactor should never run below 20% of its capacity. Even though the capacity was below 10%, the team of operators and engineers decided still to proceed with the experiments it was supposed to conduct. One reason for conducting the experiments was time pressure. They had to be completed within a specific time frame. A second reason for proceeding was that this safety violation was probably not the first time certain safety rules have been violated in the past without any negative consequences. But this time, it had negative consequences that were also triggered by further decisions, ultimately leading to a double explosion of the core and to the release of radioactive materials into the atmosphere.

One could refer to many other examples of human error in industry and other domains of life. Such examples include the analysis of operational problems in nuclear power stations (e.g., Dhillon, 2017; Nascimento & Mesquita, 2012; Rasmussen, 1980; Vicente, Mumawz, & Roth, 2004), human error in medicine (e.g., Bogner, 1994), human error in mining (e.g., Ruckart & Burgess, 2007; Simpson, Horberry, & Joy, 2009), human error in aviation (e.g., Erjavac, Iammartino, & Fossaceca, 2018; Wiegman & Shappell, 2003), human error in rail incidents (e.g., Baysari, Caponecchia, McIntosh, & Wilson, 2008), human error while driving (e.g., Eboli, Mazzulla, & Pungillo, 2017; Stanton & Salmon, 2009), or human error contributing to collisions of oil tankers (e.g., Brenker, 2017; Martins & Maturana, 2010).

Such analyses are necessary and highly important. First, they consider the complexity of the life domain and the specific situation. Second, they are ecologically valid because they refer to real-life events. Yet, they also have some methodological problems (see also Lipshitz, 1997). Many analyses of errors in naturalistic contexts are retrospective. One starts with the negative unintended outcome and tries to identify errors that led to this outcome. This sampling method has been called outcome sampling and the many problems related to it have been described in detail (e.g. Dawes, 1999; Fiedler, 2000). Researchers might perceive different factors as crucial for the development of a problem and come up with different explanations for the same disaster. Such post-accident analyses can also fall for the hindsight bias – in hindsight it seems easy to identify the strategy that led to failure, when at the time the situation actually occurred, the outcome was not easily foreseeable (Fischhoff, 1975). Most people in these disaster situations are not lacking in intelligence, nor did they behave irresponsibly. It is possible for bad outcomes to happen as a consequence of sound decision strategies and as a consequence of the best intentions. In personal life, one can decide to go jogging regularly to reduce the risk of heart disease, but then step in a hole while not paying attention to the road and hurt the foot so badly that surgery becomes necessary. Therefore, the goal for the current study was to observe human error in complex, uncertain, and dynamic problem situations in the laboratory while individuals and teams worked on these simulated problem situations and to come up with a taxonomy following the step-model of problem solving and decision making. For methodologists, instead of using outcome sampling, we used predictive sampling (e.g., Fiedler, 2000).

1.3. Microworlds

Instead of such retrospective analyses of real-world human errors leading to disasters, we followed a different approach. We observed participants in several experiments and training programs working either alone or in small groups with different microworlds. Microworlds are computer-simulated scenarios that reflect characteristics of real-life problems (Brehmer & Dörner, 1993) and are also used in the field of gamification (see meta-analysis of Sailer & Homner, 2020; Ulrich, Boring, & Lew, 2019). They are complex, in that they consist of many interconnected variables; dynamic, in that the problem situation develops and changes over time; and uncertain, in that problem aspects are novel or unknown to the problem solver (Frensch & Funke, 1995; Osman, 2010). Participants working on these microworlds receive detailed instructions and take on a specific role, then search for information, plan, and make decisions that are implemented in the computer. These decisions then lead to changes in the situation (together with some programmed events in the simulation that are reported to the problem solver) and then participants engage again in information collection, planning, and decision making (Dörner & Funke, 2017; Funke, 2010; Schmid, Ragni, Gonzalez, & Funke, 2011). Participants' decisions along with changes in the problem situations are saved automatically in log files.

As the microworlds we used exhibit characteristics of real-life problems such as complexity, uncertainty, and dynamics, it makes them close analogues to the real world and allow for the study of decision-making errors. Our goal in observing participants in different microworlds with different demands was to allow the collection of a number of human errors, which we would then report according to the steps of problem solving and decision making.

1.4. The steps of problem solving

Theories of problem solving (e.g., Bransford & Stein, 1993; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Sternberg, 1986), decision making (e.g., Galotti, 2002; Klein, 1998), complex problem solving and action regulation (e.g., Dörner, 1996; Fischer, Greiff, & Funke, 2012; Güss, Tuason, & Gerhard, 2010) distinguish six different steps, sometimes using slightly different terminology:

(1) Problem identification – the first step involving the realization that there is a problem. This seems to be an obvious step, but it is a crucial step. If an alcoholic, for example, does not realize that he or she has a problem, then any form of therapy will be unsuccessful;
(2) Goal definition – problem solvers define goals, clarify unclear or abstract goals, and balance contradicting goals. Goals provide direction in the problem-solving process (e.g., Locke & Latham, 2002; Osman, 2008);
(3) Information gathering – problem solvers search for information and organize it into a mental model of the situation;
(4) Elaboration and prediction – problem solvers reflect on possible causes of the problems and make predictions regarding possible future developments;
(5) Planning, decision making, and action – to reach their goals, problem solvers develop possible action sequences. Before implementation, action sequences are evaluated, and decisions are made about their applicability and potential success;
(6) Evaluation of outcome and self-reflection – problem solvers self-monitor, assess what they have done, modify their approach, and potentially engage in self-reflection, analyzing, for example, their own role during the problem-solving process (e.g., Osman, 2012; Donovan, Güss, & Naslund, 2015).

The problem-solving steps are not a linear process but rather a recursive and iterative one, depending always on the current situational demands. Thus, the problem-solving and decision-making process of a person can be described through this step model. As it turns out, errors can occur in each of the steps and hence this scheme is also useful to classify errors in the process of problem solving.

1.5. Study goals

As discussed, there exist attempts to classify human error in different situations, but none of the existing classifications can be applied to human decision making and problem solving in complex, dynamic, and non-transparent situations. The goal of the current study was to describe a taxonomy of errors shown in such situations by using different groups of participants with different background characteristics and by using three different simulations with different task characteristics. The list of errors is organized according to the common steps of decision making and problem solving. Like an ethnographer we attempt first to observe the breadth of possible error behaviors while participants work on these simulated environments and then discuss and justify why they are considered to be errors. We then analyze the causes of these errors.

2. Method

2.1. Instruments

2.1.1. CHOCO FINE

CHOCO FINE is a business simulation, a top management game (Dörner & Gerdes, 1993, 2001). The simulation consists of more than 1000 simulated variables. The European Center for the Development of Vocational Training (Cedefop) and the Federal Institute for Vocational Education and Training - Germany (BIBB) endorsed CHOCO FINE as a valid training system for complex and dynamic work-related situations where decision making and action are required.

In CHOCO FINE, each participant takes the role of CEO and manages production, marketing, and sales for a period of 12–24 months within the simulation. The participant's task is to increase profit and market share of a company situated in Vienna. Participants work directly on the PC. They can search for information and implement decisions. Participants automatically receive feedback regarding financial gains and losses when they proceed to the next month. Then they can search again for information and make decisions.

The program has three screens: the main screen, the production screen, and the marketing screen. The main screen provides information about the company's product sales in the previous months and about the stock of inventory. Detailed information about the finances, income, expenses, and costs is available. One can calculate if sales cover the costs (product profitability or profit margin; i.e., sales revenue/costs should be greater than 1).

The production screen shows six machines, their capacities, and which kinds of chocolates can be produced on each of them. CHOCO FINE produces eight different chocolates. Participants can manage which kind of chocolate will be produced during what time of the month and in what quantity. Participants can also discontinue production entirely on machines.

The marketing screen shows a map of Vienna with the 23 districts shown in pie charts (see Fig. 1). The size of the pie corresponds with the size of the local market; the parts of the pie represent the market shares of the six manufacturers (CHOCO-FINE is shown in blue). Vienna Style, shown in orange on the screen, is the market leader in most districts. Thus, these pie charts show the districts in which CHOCO FINE is doing well. Participants can conduct market research referring to more detailed information regarding the districts, clients, product profiles, and competitors. Product profiles show how clients view a specific product; if, for example, CHOCO FINE milk chocolate has good "quality," and is rather "modern" or "healthy," etc. Such information is important for planning advertising campaigns and for the distribution and hiring of sales representatives.

It is important for the participant to collect detailed information about the sales situation and the time developments. Competitors' strategies, seasonal changes, and advertising campaigns all have to be taken into consideration. At one point, a low-price strategy might be appropriate, while at another time, a low-price strategy might not be appropriate. The main problem of CHOCO FINE is the overflow of information. One has to focus on the most central data and analyze the causes of certain events, for example, why yogurt chocolate did sell well in July, but not in November.

2.1.2. MORO

MORO is the interactive computer simulation of a small tribe of semi nomads (Dörner, Stäudel, & Strohschneider, 1986; Strohschneider & Güss, 1999). Whereas participants sit directly at the PC in CHOCO FINE, the MORO simulation program is handled by a facilitator who acts as the interface between the Moros and the participant. Participants have no access to the computer, but sit at a desk. (A newer version, however, allows participants to directly interact with the MORO simulation on the computer screen, Lutsevich & Dörner, 2016).

The participants are given a three-page introductory note including a map of the tribe's territory (see Fig. 2). The participant takes the role of a developmental aid assistant over a period of 20 (simulated) years and tries to improve the living conditions of the Moros. The tribe lives at the southern rim of the Sahel Zone. The living conditions of the roughly 500 Moros are difficult. They live primarily from millet and cattle. Women, children, and the elderly work on the fields. The men work with the

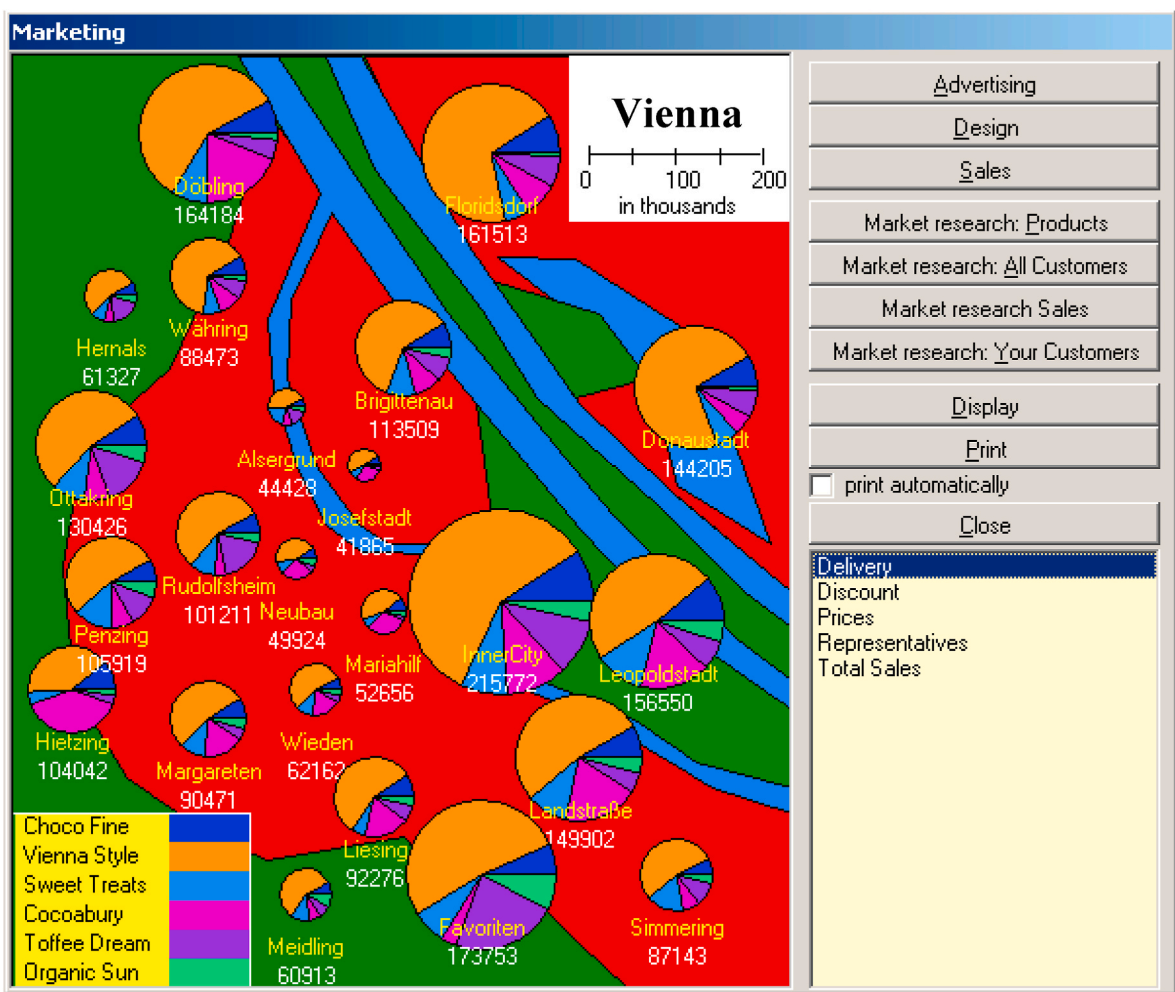

Fig. 1. Marketing screen of CHOCO FINE.

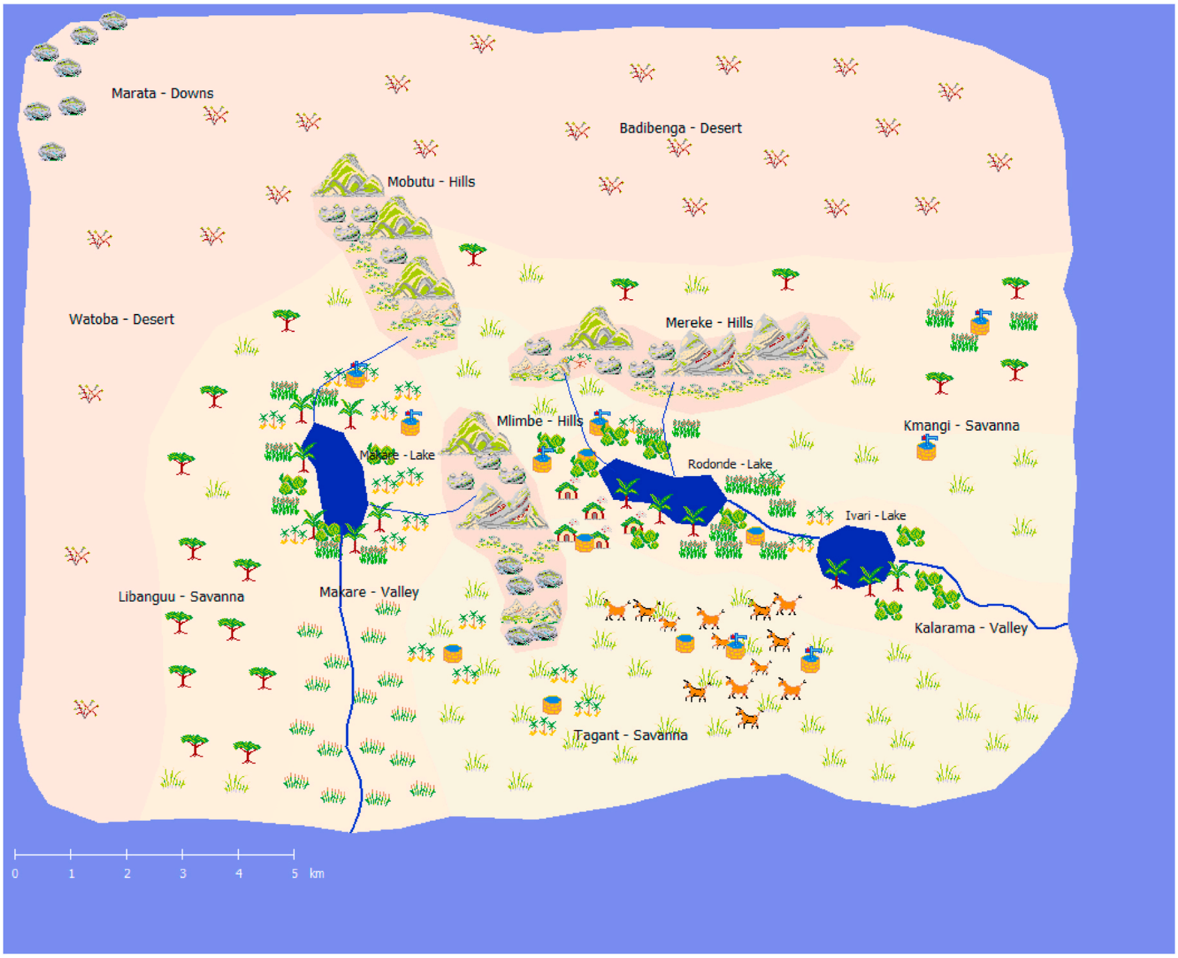

Fig. 2. Map of the MORO country.

cattle in the savanna and semi-desert. The living expectation is quite low. Famines are not rare.

Participants ask the experimenter for information they would like to know. They can inquire, for example, about the number of cattle, millet yields, infant birth rates, cash in the bank, intensity of the Tsetse-plague, ground water level, rain fall, and so on. There are 45 variables that can be assessed. If the participants require more general information, such as the social structure of the Moros or cattle breeding details, the program has access to a number of text files that contain this background information. The experimenter accesses these text files and reads them to the participants. If the situation deteriorates considerably or if the Moros have complaints, the system provides either "alarm messages" or "complaints" on the computer screen, which are then read to the participant.

Participants have a certain amount of money available as loan for their decisions, for instance, for building wells, setting up a field hospital with staff, buying and selling cattle and millet, or purchasing fertilizer. Since the money is a loan, it is expected that participants not only spend but also earn money, for example by selling excess food items. The program provides 25 possible actions. Participants are not provided with a list of these possible decisions but have to develop their own problem solutions. Sometimes participants develop measures that are not implemented in the program (e.g., developing tourism, or acquiring additional money from the UN). In these cases, the experimenter refuses those decisions providing a plausible explanation.

MORO is highly complex in that its variables are interrelated and it is uncertain and opaque, because not all the important variables are immediately obvious (like groundwater level or grass consumption by the cattle), and because feedback is often time-delayed. The main task for participants during the MORO simulation is to avoid disasters. Such disasters can be a result of low ground water level and extensive water use from wells or irreversible overgrazing, which, in turn, is a result of a dramatic increase in number of cattle. These disasters develop very slowly and one has to constantly gauge the balance of the system, considering the interconnectedness of all the variables.

2.1.3. WINFIRE

In WINFIRE (Gerdes, Dörner, & Pfeiffer, 1993; Schaub, 2010), participants take the role of a fire-fighting commander who tries to protect cities from approaching fires. Participants sit directly at the PC on which they see wind strength and direction, red fire-fighting units and yellow helicopters, burning fires, cities, and lakes (see Fig. 3). When they click on a unit with the right mouse key, they see the possible command options such as patrolling or extinguishing fires.

WINFIRE is less complex compared to CHOCO FINE and MORO, but it is highly dynamic and uncertain, because fires start at different times and in unknown locations and their development is influenced by changing wind direction and strength (for similarity to demands for "real" fire fighters, see Baumann, Gohm, & Bonner, 2011). Participants can distribute their helicopters and fire-fighting trucks around the cities and surrounding forest. They can clear forest to avoid spreading of fires. They can let the units patrol independently in areas they define and give them orders to extinguish fires.

The main problem in WINFIRE is the speed of unfolding events. The simulation puts the decision maker under time pressure and requires quick and decisive actions. Slow actions would result in fast-spreading

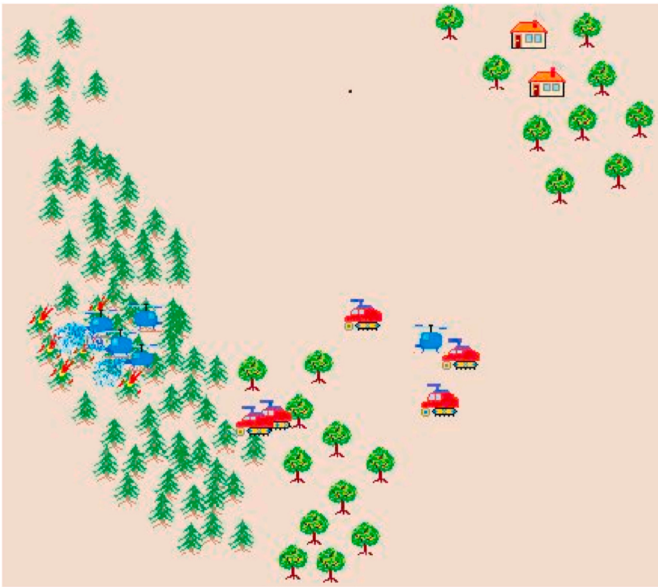

Fig. 3. Computer screen of the WINFIRE simulation.

fires.

2.1.4. *Comparing CHOCO FINE, MORO, and WINFIRE*

The three simulations have different characteristics and pose different challenges for the problem solver. They require different strategic approaches and different decision making (see on the role of strategic knowledge Schoppek, 2002). CHOCO FINE is the most complex regarding the number of simulated variables. MORO is the most opaque because of the unknown relationships of the interconnected variables. WINFIRE is the most dynamic regarding the number and speed of unfolding events. CHOCO FINE and MORO are often played over a period of 1.5–2 h. WINFIRE is often played for about 15 min., to contrast the three simulations, we have to oversimplify. In CHOCO FINE, the main problem is the information overload. Participants can easily get lost in the multitude of data provided. Yet, they always have to consider new developments on the market, and seasonal changes. In MORO, the main problem is the balance among key variables: people, millet, cattle, pasture area, and water; planning and decision making has to consider all of these variables in their interaction. If one of these factors is not considered adequately, an imbalance happens, and disasters can easily occur. In WINFIRE, the main problems are the unknown locations of new fires and the quick spreading of fires. Participants have to strategically position their units and act quickly.

Table 1 summarizes the different characteristics of the three microworlds CHOCO FINE, MORO, and WINFIRE.

Table 1
Characteristics of the three microworlds CHOFO FINE, MORO, and WINFIRE.

	CHOCO FINE	MORO	WINFIRE
Content/topic	Marketing/ business company	Living situation of small tribe in Sahel zone	Protecting forest and towns from fires
Complexity: number of simulated variables	Over 1000	65	30
Dynamics	Events between months (e.g., seasons, competitors)	Time-delayed effects and side-effects of decisions	Spreading of fires
Uncertainty due to	Overflow of information and high complexity	High interconnectivity of variables	Locations of fires initially not known and quick spreading of fires
Duration	1–2 h	1–2 h	15 min
Possible actions	Over 100	25	7 possible commands for each unit
Feedback of decisions	After decision are made for a month, system records and reports effects	Key variables can be accessed	Screen shows if extinguishing fire was successful or not
Length of time to learn the task	20 min	10 min	5 min
Instructions	3 pages	3 pages	2 pages
Clarity of goals	Clear "increase profit and market share"	Unclear "improve living conditions"	Clear "save forest and people"
Performance assessment	Total monies after each month	Moros alive, Cattle alive, Pasture area, Monies	Percentage of saved forest and number of saved houses

2.2. *Participants*

Our goal was to get a big and heterogeneous sample regarding age, gender, profession, and culture. Therefore, our error analysis is based on several different subsamples. First, participants were 75 German and Austrian managers who participated in groups in 5 training programs on "Complexity Management and Dynamic Decision Making". We did not assess their ages and gender in these training programs but would estimate the ages to range between 30 and 60 years. About 70 percent were men and 30 percent of the managers were women. These participants worked on MORO and/or on CHOCO FINE.

Participants were also 535 students from different countries: Brazil (n = 97), Germany (n = 104), India (n = 97), Philippines (n = 104), and United States (n = 133) who worked individually on WINFIRE (see Güss, 2011). Their ages ranged from 18 to 49 years with an average age of 22.1 years (*SD* = 4.44). Samples were from schools of arts and sciences, social sciences, and business and comparable according to course or major and gender; 63 percent were females.

Participants were also German (N = 58) and US (N = 56) students who worked individually on MORO. Participants' age ranged from 18 to 49 years (*M* = 23.16, *SD* = 5.16). 76.3 percent of participants were female and 23.7 percent were male. Participants from the two countries did not differ regarding age and gender.

2.3. *Procedure and data collection*

Participants worked either alone on a microworld or in a small group of up to four participants. Participants read first an instruction sheet for each simulation before the actual simulation started so they could familiarize themselves with the microworlds. Participants could always ask the experimenters when they had questions regarding the microworlds. The authors collected the data and observed participants while they worked on these simulations. The WINFIRE participants were instructed to think aloud while they worked on the simulation. The authors took notes while observing the participants.

3. Results: 24 errors and their causes

In the following section, we describe 24 errors observed in the three simulations by the authors. Although the same errors can happen in one or more of the three simulations, we provide only one example for each error. For all errors, we explain why they were errors and provided possible causes for them.

3.1. Problem identification

3.1.1. Denial of reality: **"What I don't know, won't hurt me!"**

While playing CHOCO FINE, one team did not realize that the competitor Cocoabury had increased its sales. The expansion of this company could be seen easily in the pie chart on the marketing screen. The pie chart showed the competitors of CHOCO FINE in the various city districts. Although the team discussed the market leader Vienna Style, it did not talk about Cocoabury, who had become the market leader and displaced Vienna Style. The expansion concerned the lower-class districts, such as Favoriten, particularly. It could be easily seen when comparing competitors' prices in the marketing menu that this expansion was a result of Cocoabury's aggressive low-price strategy.

It was possible to lower the prices of CHOCO FINE products and still make a profit if the sales numbers increased. However, the production costs of Cocoabury were much lower than those of CHOCO FINE, therefore this strategy might not work in the long run. Costs for production and prices for merchants could be easily compared. The team of participants, however, never discussed this alternative as they never realized Cocoabury's market shares were growing so quickly.

This was a denial of reality. One may avoid realizing and identifying difficult problems so that the strategy will not need to be changed. It may seem easier to stick to beliefs about the world rather than dealing with the "real" world. The cause for this idealistic strategy was probably fear of being unable to cope with the real situation.

3.1.2. Overgeneralization of a successful plan: **"What has worked in the past, will work in the future!"**

It is advisable in a complex situation to look for those factors that are currently the main obstacles to reaching a goal. One group of participants analyzed the sales situation in CHOCO FINE and came to the following conclusion: "It is the missing orders! We have to do something to increase the sales!" They were absolutely right! They then made some decisions to increase sales, which were successful. At a later point, the team had similar problems with sales of a specific product. They naturally assumed the same causes and made the same decisions.

This time they were ineffective because the central factors were different. Following affirmative information collection, they only considered information that was similar to the previous situation. However, this time the low sales numbers were a result of the low number of sales representatives (or low selling capacity). This possibility was not considered, and relevant information was not gathered simply because, as one member stated, "we knew how the sales work[ed]," thus they only chose to consider the information they wanted to consider.

This is a form of overgeneralization. "Problems with sales are caused by low demand!": Overgeneralization of a successful plan because of inadequate situation analysis and insufficient collection of important information. Since the team had initial success following this hypothesis, it was rewarded. As a consequence, methodical rigidity resulted in how to solve problems related to low sales. Methodical rigidity is a result of the conviction, "We know how to do it!" This strengthened the feeling of competence.

3.1.3. Status-quo thinking, not considering time developments: **"There is no fire, so I can wait! Why care about problems which do not yet exist?"**

When participants begin the WINFIRE simulation, they see a screen with forest, villages, lakes, fire-fighting trucks, and helicopters. It is common for participants to say, as one participant did, "There is no fire, so I can wait!"

This is an error. Sure, it is unknown where the fires will start, but it takes time for the fire-fighting units to reach a fire destination. Participants have seen this in a similar trial version they played to become familiar with the simulation and the commands. In order to be prepared, it would make sense to distribute the units over the forest and close to the villages before potential fires start.

This error is related to not recognizing the problem situation. A part of the problem situation is the realization that the fire-fighting units are relatively slow, and fires can spread quickly. Some participants did not think so far into the future and did not consider these important time developments. By the time a unit arrives at a burning fire, the fire could have already spread. This error is similar to the denial of reality in error 1.1. "When no problems show up, then there is no problem!" Not thinking about the future and possible related problems helps to preserve one's feeling of competence.

3.1.4. Inaccurate perception: **"The main direction is ok!"**

Once a fire starts in the WINFIRE simulation, the participant gives the command to a fire truck to drive to the starting fire and to extinguish the fire. The participant clicks on the exact location where the truck should drive. However, the location one participant in our study selected was a location where the forest had already burned, which was indicated by an image of grey ashes on the screen.

While it can make sense to extinguish the glow of burned down trees, it would have made more sense to select the area nearby where more fires were starting. The participant intended to send the truck to a burning fire and simply did not examine the details on the screen.

The reason for this error could be a low resolution-level of perception, i.e., perception is very general and not very detailed. One does not perceive the details on the screen, but only reacts to the general view one has of the situation. This low resolution-level, in turn, could be caused by the experience of time pressure, in which quick actions are required. The ability to react quickly in an uncertain situation provides a feeling of not being at the mercy of the situation, i.e., it strengthens the feeling of competence.

3.2. Goal definition

3.2.1. Goal definition and status quo thinking: **"It is good the way it is!"**

During the MORO simulation, one team engaged in a discussion about the goal of "possible extension of crop or pasture areas." After a brief analysis of the harvest and earnings of the current pasture and crop areas, the team realized that it was enough for the cattle. Therefore, the idea of extending the area was not pursued further.

This is an error because only the current situation, the status quo, is taken into consideration. What the team did not consider was the potential increase in number of cattle caused either through reproduction or by other measures such as purchasing cattle. Therefore, extending the pasture and crop areas could be a worthwhile pursuit.

In this case, status-quo thinking was related to a discussion about the goals within a team. Status-quo thinking does not consider time developments. The team stopped elaborating possible future developments and long-term effects of actions. One reason for this behavior is the tendency to avoid difficult problems. To save time and to proceed, an elaboration and analysis of possible actions and consequences is stopped, and increased uncertainty is avoided.

3.2.2. Secondary goals determine actions: "**In this city lives the mayor. He does not do anything for the people. Let the house burn.**"

The WINFIRE screen shows three small cities with different demographics. According to the instructions provided to participants in one WINFIRE experiment, in one of the cities lives the mayor. Several governmental buildings such as the city hall are located in the same city. One participant from abroad said: "In this city lives the mayor. He does not do anything for the people. Let his house burn." The participant's goal meant that fire-fighters should not intervene.

Although such a goal reflected the political opinions or experiences of the participant, letting the mayor's house burn can have unintended consequences. As a result of the participant's decision, the whole city burnt down and the fires even spread to the neighboring forest. This could have been avoided if fire-fighting units had attempted to extinguish the fires in the city.

Goals can reflect personal experiences and values and these can directly affect problem-solving actions (Güss, 2011). Yet unintended consequences of the goals/actions were not considered. By sticking to values and opinions, a problem may be solved which is not a part of the task. One may have a better feeling of competence this way, but the danger may increase as a result. To burn down the mayor's house was not at all an ordinary task in the fire-fighting game. But to be able to do it giving in to a feeling of revenge, imparts a feeling of power and hence increases the feeling of competence.

3.3. Information gathering

3.3.1. Entrenchment – Too detailed resolution level of information collection (Analysis paralysis): **"You have to know everything before you act!"**

Many groups and many individual participants start with a detailed analysis of the situation. The CHOCO FINE computer screen provides detailed tables of sales, expenses, product profiles, etc., and many participants engage in taking detailed notes and beginning calculations. This was also the case for some groups working on the MORO simulation. We had groups who were assigned 3 h to work on 24 simulated months as developmental aid assistants to help the Moros. Some groups spent 90 min before they made and implemented the first decision. It seemed that many participants avoided starting to make decisions.

Such a behavior is problematic for several reasons: First, it is impossible to collect *all* information in a complex system. This would require an endless amount of time, which is not available. Second, most of the available information is *not relevant* for the necessary actions. Therefore it is necessary to reflect on what kind of information one would need. Questions such as the following could be relevant: "Who eats a lot of CHOCO FINE chocolates? Who eats little chocolate? What is the product profile of the successful brands?" Third, the events in a complex situation are never solely dependent on the current situation, but also on previous developments. Data on previous developments are not available at the beginning of a simulation.

The main reason for this cognitive error is probably the maxim, "If you want to act successfully, you have to collect a lot of information and a lot of detailed information." The problem is the wrong resolution level of thinking. The maxim becomes a promising one if it is modified to: "Search for a lot of information in key domains with an adequate resolution level."

As easy as it sounds, following this maxim is very difficult. What is the adequate resolution level? Which domain is currently of central relevance? It is, for example, enough information to know in which part of the city CHOCO FINE chocolates are sold most and in which part of the city they are sold least. Then one can look for the client profiles in these areas. The resolution level would be too high if someone investigates the sales of all CHOCO FINE products in all the 23 different districts of the city. That much information would become overwhelming and an individual would have difficulty integrating so much information in a meaningful way.

Determining the relevance of domains is not easy and always depends on the context. Sometimes the prices of the products are important; sometimes the client profile in a specific part of town is a key variable. Sometimes participants have to react to new products launched by competitors.

What could be the reason for such an overly detailed information collection? One possible explanation is related to the demands of the situation. Being confronted with CHOCO FINE for the first time is overwhelming and it is hard to know what to do. Yet, one knows how to write down tables and make calculations. Thus, an individual's feeling of competence is protected by engaging in known behavior and avoiding action in an unknown domain. This behavior has been labeled entrenchment in irrelevant but manageable domains (Dörner, 1996).

Trying to analyze *all* information as mentioned before is not possible. Yet, later individuals and groups have an excuse if they fail to manage the complex problem successfully. "It was impossible to get all the relevant information. How can someone plan adequately without having this kind of information?" Additionally, collecting information can be considered as a very meaningful activity as a preparation to act. "We do something which is very important!" Thus the collection of information increases the feeling of competence. On the other hand, direct action is avoided; hence, the risk of failure is also avoided. This is a very good method to do something meaningful, but to avoid doing anything to expose an individual or group to the dangers of real action.

3.3.2. Misinterpreting information: **"If nothing changes, then it is useless."**

The tsetse fly is dangerous to the Moros' cattle. One team stopped fighting the tsetse fly while working on the MORO simulation because they did not see an effect from the insecticides from one year to the next. "Before we had about 30,000 hives, now we have 30,500!" The insect population remained constant.

The mistake here is that the team did not realize that "no effect" could actually be an effect. Their action of applying insecticides had the effect of keeping the tsetse population from increasing. This is definitely an effect. As a consequence of the team's decision to stop fighting the tsetse fly, the fly population rose, which, in turn, had catastrophic consequences for the number of cattle.

This misinterpretation of numbers is related to not considering the numbers as a part of a system of variables and not considering what the causes are and what the consequences are. The thinking falls short. Again, this may be due to the human motivation to make things simple. When things are simple, it is no longer necessary to think about them, giving the illusion that one knows what is going on.

3.3.3. Perceptual defense in teams: **"Stick to your action!" or "You see what you want to see!"**

One CHOCO FINE team discussed advertising options and what aspects of their products they wanted to emphasize. They made the decision to "highlight the modernity of their products!" They advertised accordingly. Afterward, the team conducted market research and analyzed client profiles. They wanted to know what the clients wanted. This analysis showed that the emphasis in advertising was wrong. The clients did not really care about the modernity of the products. However, the team's analysis of the client profiles did not lead to a change in their advertising.

At first glance, it is hard to understand how such a decision-making error is possible. The team searched for relevant information, yet did not address the conflict between the new information and the decision they made. There was a denial of the conflicting information, thus, the conflicting information was not regarded – a phenomenon called perceptual defense.

One possible reason for not addressing this conflict was that the team was simply fed up with discussing advertising (see Janis, 1972). The team had made the decision and now should stick to it – also, for the sake of group harmony. Perhaps the team was afraid regarding the uncertain outcome of a new discussion. Thus, preservation of the feeling of being on the right path may have been the primary motivation for not dealing with the conflict. The team did not realize that modernity did not play an important role in clients' perception of the product. This example was not an exception. Several times, teams did not see what they did not want to see (more on this follows below).

3.4. Elaboration and prediction

3.4.1. Overgeneralizing conclusions: **"Gone is gone!"**

While working on CHOCO FINE, one group of participants realized that the demand for a specific product was not satisfied in the previous month. A member of the group said, "Once the clients are gone, they will never return!"

This statement reflects a form of overgeneralization. Sometimes the conclusion is valid, but sometimes it is not valid. It is valid if competitors developed a similar product and are selling it. It is not valid if the profile of the specific product reflects the clients' desired product profile and no similar product is currently available on the market. Then clients will return to the product even if it was not available for a while.

The cause for such overgeneralizations could be the desire to find simple decision rules quickly in an uncertain situation. Such overgeneralizations create certainty and security, suggesting that one has found the rules for successfully managing the system. Thus, they are directly related to the motivations to reduce uncertainty and maintain competence. Such overgeneralizations can be very helpful if one is aware that they are potentially false hypotheses. These hypotheses describe a certain event and can serve as a starting point for longer reflections and clarifying discussions as they may provoke reactions from other group members. Again, this seems an example of the tendency to make things simple in order to avoid thinking about difficult problems.

3.4.2. *Lack of analysis of problem causes:* ***"If we cannot sell this stuff, then we should not produce it."***

As a team analyzed the results of their actions during one month of CHOCO FINE, one participant said: "We did not sell anything; therefore we need to reduce our production."

This is bad advice because reduction of production is not the sole option to deal with loss in sales. It would be useful to analyze first *why* the sales dropped and whether the drop was substantial.

Why did this team fail to engage in further analysis of the causes? One possible reason is the ease of reducing production. It is more of a reaction than a thought-through decision alternative: "Sales are down, then also production should be down; otherwise we produce for nothing." The reason for lowering the production numbers could be the desire to control the situation. Lower production numbers definitely mean fewer products. One has control and can see effects. Other options are more risky. Would advertising help? In brief, the reason for the suggested decision could be the need or search for control. This is yet another example of making things simple to avoid thinking about a difficult problem.

3.4.3. *Not considering the interconnectedness of system variables:* ***"1000 is enough!"***

One team stated the following wrong hypothesis: "If the Moros slaughter every year 150 cows, and if the growth rate of cows is 25%, then 1000 cows should be enough to feed all the Moros; because if you have 1000 cows, there will be every year 250 new ones." This hypothesis led the team to sell all cattle beyond the 1000 they thought they needed. As a result, the team initially had very good revenues.

Yet, several aspects of this hypothesis are wrong. First of all, a cattle herd that consists of young cattle does not have a growth rate of 25% per year, but of 0%. One has to consider the age distribution of the cattle herd. Second, quite a number of cows die because of the sleeping sickness. Thus, a cattle herd of 1000 does not remain a cattle herd of 1000. Third, the number of slaughtered cows increases with the growing Moro population.

Thus, the hypothesis is too simple and does not consider the interconnectedness of the system variables, as well as the time developments. The consequence of the team's decision was a steep decline in the number of cattle. The team had to spend a lot of money to buy additional cattle to reach the necessary number of about 2800. The cause of this thinking could be the motivation to foster a feeling of competence through taking an action, which will provide good results in the moment. The team members did not consider or question the information leading to their hypothesis.

3.4.4. *Wrong causal attribution:* ***"We have it, the people want to buy it, but we don't sell it!?"***

One CHOCO FINE team realized that they had a high demand for nut chocolates, along with a corresponding production during the last month, but, unfortunately, had low sales. This apparent contradiction was explained by the fact that the dealers had asked for the product, but then had switched to another company "because they must have made better offers than we made."

The team engaged in a search for causes. Although easily visible in the production table showing four weeks of production, the team did not realize that the production for nut chocolates happened during the second part of the month. During the first part of the month, nut chocolate was not produced.

The reason for this wrong causal attribution was not paying attention to the time developments of production and sales. A simple explanation was given and accepted, and the lack of coordinating production and sales was not realized. Like several errors we have discussed before, the team stopped thinking and analyzing the situation, which may be motivated by the tendency to maintain the feeling of being able to master the problem.

3.4.5. *Oversimplifying hypothesis:* ***"If the clients really want it, then they are willing to pay more for it!"***

One team thought they could increase the price for bitter chocolates, because the sales for bitter chocolate were very high.

This was a mistake, because the low price was one of the main reasons why so many people bought the chocolate. This is a further example of an over-generalized hypothesis, which does not take into account the many important factors of a purchasing decision. This is an example of decontextualized actions: "If we sell so much of this stuff then we can increase the price and will earn more!" After increasing the price, "the stuff" did not sell well, and they did not earn more, but less.

The cause for this erroneous hypothesis was not considering sales as part of a system, both influenced by several factors and influencing several factors. It was narrow thinking, potentially due to the tendency to make things too simple and thus preserve the feeling of competence.

3.4.6. *Analogia Praecox:* ***"What they can do, we can do as well!"***

One CHOCO FINE team was analyzing the milk chocolate product profile of the competitor Vienna Style, because Vienna Style was selling milk chocolate successfully. The team modified its own milk chocolate, adjusting it to match that of the competitor. "If Vienna Style can sell it, then we can sell it too!"

This strategy went wrong as Vienna Style had a totally different profile and a different market position compared to CHOCO FINE. Vienna Style chocolates particularly appealed to "yuppie" clients. CHOCO FINE, however, had no special relationship with this group of customers. Thus, the newly designed chocolate did not sell better, but worse, than before. CHOCO FINE's own clients did not like the new chocolate, nor did the new chocolate appeal to Vienna Style's clients.

This error is an example for an analogia praecox. The use of analogies, per se, is a very useful and often creative way of solving problems. If the analogy is transferred without considering the conditions in detail, it is not a useful problem-solving technique. This form of analogy can also be regarded as methodical rigidity – one simply copies what others do. This can be successful if the conditions are right. In this case, they were not. Again, this seems to be an example of developing too simple an idea of the situation. By accepting a simple solution, it is possible to preserve the feeling of being able to master the problem.

3.5. *Planning, decision making, and action*

3.5.1. *Methodical rigidity:* ***"Arithmetic is always good!"***

Many groups in CHOCO FINE discussed how to come up with possible decisions, for example, which kind of chocolates to push more (e.g., milk chocolates or hazelnut chocolates or bitter chocolates). Some groups decided to analyze the sales for each kind of chocolates and calculate the profit by subtracting the costs, then to push and produce more of those chocolates with the highest values.

Such a behavior is problematic for several reasons: First, it does not take into consideration that the product or profit margin is calculated from time to time and is not a constant number. The current costs are related to the current sales. Thus, the product or profit margin can provide an incorrect view of the situation. If production of a certain kind of chocolate is low and the sales are high, the result will be a high product or profit margin. This limitation to calculating the product or profit margin was discussed in the instruction sheets provided to the participants.

Second, pushing only a few chocolates is a conservative method. Only the products that have sold well will be pushed. The market, however, is relatively unstable and dependent upon various factors such as the season, competitors' strategies, clients' changing preferences, and changing demographics in the different parts of town. Such a rigid form of calculation does not take into consideration the many other factors that influence sales.

Developing such a mathematical format as a basis for decision making makes the group feel good and increases group harmony. The group is making more or less complicated calculations to control the situation, which results in an increased feeling of competence. The reasoning of the group is that the development of such a mathematical format negates the need for further thinking. It is only necessary to put the appropriate numbers into the format and everything is done. Constant reflection upon decision alternatives is no longer necessary and the uncertainty of the situation is reduced. The group can simply make calculations and feel competent in doing so. Methodical rigidity goes back to the motivation to reduce uncertainty related to the choice of an action and to increase one's feeling of competence. Additionally, the ability to use mathematics to solve a problem makes people feel great, as mathematics is considered a high-ranking mental activity.

3.5.2. *Tough decisions: **"We knock out milk chocolate!"***

The sales of milk chocolate in CHOCO FINE went down slightly and the group engaged in a discussion about completely stopping the production of this chocolate.

This could be problematic, because variation in sales is normal in a specific market and may not be of special importance. Unless the drop in sales is dramatic, one should probably resist such a strategy.

The reason for such a charged decision may be the need to demonstrate competence. The specific chocolate is "personalized" and "punished" for the drop in sales by eliminating it from the portfolio. The decision indicates to the group members that they have done something very strong and bold.

3.5.3. *Avoiding making decisions: **"Look before you leap!"***

Participants avoid and prolong making decisions, partly because they want to understand the whole situation and partly because they want to develop general long-term strategies.

Such an approach is problematic for two reasons: First, the whole CHOCO FINE situation is initially unknown and it makes sense to detect and observe developments. Without knowing time developments, referring, for example, to seasonal changes, participants do not have data to develop strategies. The laws of time in a specific system can only be understood if one observes them.

Second, strategic planning that is too detailed is not appropriate in a system like CHOCO FINE, which is loaded with information. Contrary to the MORO simulation, it is almost impossible to detect all the interactions between variables even on a rough level. Besides, many variables change over time. Therefore, it is necessary to follow a "muddling through" strategy (Lindblom, 1959), so that one allows learning over time.

The main reason for avoiding making decisions is probably the experienced insecurity. One tries to deal with this insecurity and to gain certainty and control by attempting to develop detailed plans. Detailed planning means doing something very important; it is a prerequisite for successful decision making. On the other hand, by avoiding action, the risk of failure is avoided.

3.5.4. *Overplanning and horizontal flight: **"Well just make a plan …"***

One team working in CHOCO FINE developed a detailed strategy for production and sales, which entailed many mid-term and long-term goals. Later it turned out that this strategy could not be implemented because it could not be adapted to the concrete events happening in the simulations.

Planning for a reality one does not even know for certain exists is an example of overplanning. One flees into a controllable domain and attempts to do what one knows best, namely developing detailed plans, regardless of whether these plans can be implemented later. Overplanning relies on assumptions that one can predict exact developments and ramifications of events. But when the situation changes in a completely unexpected direction, when something happens that was not part of the expectation horizon, then one becomes helpless. The plan does not work! Many assumptions made about the world and used to develop the plan were wrong.

The main reason for overplanning and horizontal flight may be the desire to reduce uncertainty by elaborating on a specific expectation for how a situation would develop and a plan for how one could act in response. Such a detailed plan gives the illusion that the situation is under control, which enhances the feeling of competence. Overplanning entails the non-consideration of certain conditions for developments. If all possible conditions were considered, the problem space would grow exponentially and would not be manageable. While overplanning, only part of the problem space is considered, but there is a high likelihood it is the wrong part. Very similar to 5.3, planning gives the feeling of doing something very important; it is the prerequisite of success. On the other hand, avoiding action can lead to failure.

3.5.5. *Underplanning and actionism: **"Who dares wins!"***

Instead of overplanning, one group in MORO did the exact opposite. The team did not engage in a discussion about goals or strategies. Instead, the team made decisions and took action right away in addressing the needs of the Moros as provided in the instructions: "too little water"; "number of tsetse flies has increased." The team drilled deep water wells and hired a company to spray insecticides against the tsetse flies.

The initial result was an increase in cattle. The cattle herd then ate all the grass and destroyed the vegetation, which could not recover. So "who risks, wins," perhaps wins only in the short-term and only once. This method of decision making does not regard side- and long-term effects. It is very dangerous and might only be permissible under extreme time pressure and when otherwise everything else is lost.

The reason for this error is probably the relief of quick actions under experienced time pressure. Action frees one from the feeling of weakness. "The Moros are suffering, so we need to help them quickly." Time pressure often leads to quick action and to superficial reflections about situations and actions.

3.5.6. *Single-focus strategy and lack of multi-tasking: **"First things first!"***

During the WINFIRE simulation, several fires start in different locations of the forest. Some of them are small and go out by themselves; others spread depending on the wind direction and strength. One participant said, "I will deal with this one fire first." He sent trucks and helicopters to this fire; he cut trees and tried to control the fire. This single fire caught all his attention.

Focusing only on one fire was an error. In the meantime, two other fires started and spread quite quickly, endangering the nearby cities. The size of one of the fires became so big that it became uncontrollable for the small number of fire-fighting units and helicopters. While focusing on one fire, the other two were completely neglected.

This behavior can have several causes. One would be that the participant simply did not perceive the other fires. This is quite unlikely, though, given the bright yellow and red light of fires on the dark green screen. Another possible cause could be maintaining control to protect a feeling of competence. If the participant focuses on a manageable part of the problem environment, i.e., one small fire, then he or she can observe success in controlling that fire. The flexibility required to address three different fires at the same time could easily lead to feelings of being overwhelmed. Again, this is a form of horizontal flight. Following a familiar maxim can be reassuring, and no doubt the maxims in proverbs have their applications, but not always.

Table 2
Table of 24 errors in microworlds with examples, their causes, and related action tendencies.

	Steps of Problem Solving	Error	Quote/Example	Definition/Specifications	Motivational Cause: Strengthen the feeling of …	Action Tendency
1	Problem identi-fication	1.1. Denial of reality	“What I don't know, won't hurt me!”	Avoid realizing and identifying difficult problems	Competence	Cognitive defense
		1.2. Overgeneralization of a successful plan	“What has worked in the past, will work in the future!”	Overgeneralization of a successful plan because of inadequate situation analysis and insufficient collection of important information	Competence	Affirmative thinking or perception
		1.3. Status-quo thinking, not considering time developments	“There is no fire, so I can wait! Why care about problems which do not yet exist?”	Status-quo thinking is based solely on the current situation and does not take time developments into consideration	Competence and Certainty	Exploration
		1.4. Inaccurate perception	“The main direction is ok!”	Perception is very general and not detailed; low resolution-level of perception.	Time pressure	Exploration
2	Goal definition	2.1. Goal definition and status quo thinking	“It is good the way it is!”	Goals are developed considering only the current situation and not possible changes due to time developments and possible long-term effects of actions.	Certainty	Affirmative thinking and perception
		2.2. Secondary goals determine actions	“In this city lives the mayor. He does not do anything for the people. Let the house burn.”	Goals can reflect personal experiences and values, and these can directly affect problem-solving.	Competence	Affirmative thinking
3	Informa-tion gathering	3.1. Entrenchment	“You have to know everything before you act!”	Too detailed resolution level of information collection (Analysis Paralysis)	Competence	Safeguarding behavior
		3.2. Misinterpreting information	“If nothing changes, then it is useless.”	Misinterpreting numbers and variables and not considering causes and consequences	Certainty	Affirmative thinking or perception
		3.3. Perceptual defense in teams	“Stick to your action!” or “You see what you want to see!”	Denial of conflicting information; thus, conflicting information is not regarded	Certainty and Affiliation	Cognitive defense and Affiliative action
4	Elabora-tion and predic-tion	4.1. Overgeneralizing conclusions	“Gone is gone!”	Extrapolating inaccurate judgements	Certainty	Affirmative thinking
		4.2. Lack of analysis of problem causes	“If we cannot sell this stuff, then we should not produce it.”	Problem causes are not being analyzed.	Competence	Cognitive defense
		4.3. Not considering the interconnectedness of system variables	“1000 is enough!”	When analyzing a problem, variables are not considered as being part of a network of interrelated variables.	Competence	Affirmative thinking
		4.4. Wrong causal attribution	“We have it, the people want to buy it, but we don't sell it!?”	Wrong causal attribution of a problem because time developments were not considered.	Competence	Exploration
		4.5. Oversimplifying hypothesis	“If the clients really want it, then they are willing to pay more for it!”	Developing a hypothesis not considering the many important factors of the problem situation	Certainty and Competence	Affirmative thinking
		4.6. Analogia Praecox	“What they can do, we can do as well!”	Using an analogy without considering the conditions in detail	Competence	Affirmative thinking
5	Planning, decision making, and action	5.1. Methodical rigidity	“Arithmetic is always good!”	Following a set procedure without questioning its applicability and possible effects	Competence	Actionism
		5.2. Tough decisions	“We knock out milk chocolate!”	Charged decisions	Competence	Actionism
		5.3. Avoiding making decisions	“Look before you leap!”	Avoiding and prolonging making decisions	Competence	Exploration
		5.4. Overplanning and horizontal flight	“Well just make a plan …”	Detailed planning for a controllable reality domain that is not central to the overall problem	Certainty	Flight
		5.5. Underplanning and actionism	“Who dares wins!”	No planning of overall strategy and goal definitions, but engagement in tactical decision making	Time pressure	Actionism
		5.6. Single-focus strategy and lack of multi-tasking	“First things first!”	Focusing on one problem aspect only	Competence	Flight
		5.7. Group harmony determining team decisions	“Unity makes strong!”	The majority group opinions determine decisions	Affiliation	Affiliative action
6	Evalua-tion of outcome and self-reflection	6.1. Overconfidence	“Bitter chocolate works out well!”	Unrealistically high opinion about own judgements can lead to a lack of problem analysis	Competence	Cognitive defense and Affirmative thinking
		6.2. Ballistic action	“We are doing something!”	Taking action, not modifying it, and not controlling its effects.	Competence	Actionism

3.5.7. Group harmony determining team decisions: ***"Unity makes strong!"***

After a long and fierce dispute about the right strategy to use in CHOCO FINE, the three members of a team made peace and came to an agreement to make decisions in the future according to majority opinion. During a discussion about an advertising campaign, however, one team member made a very good proposal. The other two members did not agree. When the first team member insisted on his proposal, one of the others said in a reproachful voice, "You begin again!" The dissenting team member stopped insisting, and the team made a bad decision in accordance with the majority opinion.

The reason of this error was presumably the tendency to preserve the affiliation of the group, to protect the group harmony (see, e.g., Janis, 1972, on groupthink). Affiliation to a group is a strong source of feelings of competence.

3.6. Evaluation of outcome and self-reflection

3.6.1. Overconfidence: ***"Bitter chocolate works out well!"***

One CHOCO FINE team reflected on the results of one month during the simulation and said: "Bitter chocolate works out well, but we know that already!"

The team did not analyze *why* bitter chocolates were selling so well. The team could have analyzed the bitter chocolate profile, which could have helped them to modify profile characteristics of the other chocolates so they would sell better. In this case, the necessary analysis of causes did not take place.

The cause of this error is reflected in the statement, "We know that already!" It is a demonstration of competence; one has control over the situation and therefore further reflection is not necessary. In fact, further reflection could be perceived as demonstrating lack of knowledge or understanding. Alternately, the decision not to think further on the matter could be based on the reasoning that further consideration of something that is working would be a waste of valuable time and energy.

3.6.2. Ballistic action: ***"We are doing something!"***

While working on the MORO simulation, one team developed a detailed campaign to change the Moros' eating habits. They then invested a lot of money hiring nutrition specialists, for example. In the following simulated year, the effect of this action plan was not analyzed, though, indeed, it had a big effect. The Moros ate less beef, which would have allowed the team to sell more cattle. However, the team focused on other problems facing the Moros rather than reflecting on the outcome of their campaign.

This error can be labeled "ballistic action," which means that the action is accomplished and is not modified, and its effects are not controlled. It is like shooting a cannon ball. One cannot change its direction once it is shot.

The cause for ballistic action is probably to avoid identifying failure in order to protect one's feeling of competence.

4. Discussion

4.1. Explaining human error: PSI-theory

In the previous section, we described 24 human errors along the steps of complex problem solving and dynamic decision making. We discussed why a certain behavior was an error and attempted to provide explanations for these errors (see Table 2). Our proposition is that all the errors are not slips of action or happened because our subjects were unable to handle cognitively a complex task, but because they had the *motivation* to preserve their feeling of competence.

Since "all too often this fascination for empirical data is accompanied by the absence of an equally deep interest for theory development" (Borghi & Fini, 2019), we will elaborate in the following part on this motivational view and explain the origins of the many errors described previously referring to PSI-theory (Bach, 2009; Detje, 2000; Dörner, 1999; Dörner & Güss, 2013). PSI-theory is a computational architecture, which formalizes and describes the interaction of motivational, emotional, and cognitive processes. Its name is drawn from the Greek letter Ψ, which is often used as an abbreviation for the word psychology.

In our previous analyses, we found three main motivational reasons for the 24 errors, namely the tendency to preserve or strengthen the feeling of affiliation, to preserve or strengthen the feeling of certainty, and to preserve or strengthen the feeling of competence. The feelings of affiliation and certainty however are an important source for the feeling of competence too; the motivations to improve or preserve affiliation and certainty serve the purpose to strengthen the feeling of competence. A low competence, however, leads to anxiety and fear and so our hypothesis is that our subjects committed the errors described above mainly to get rid of the feeling of uneasiness and anxiety. Fig. 4 shows the theory in detail.

We can distinguish three basic human motivations here represented as a metaphor in three "tanks", namely one tank for affiliation, one for certainty, and one for competence (e.g., Güss, Burger, & Dörner, 2017). The "tanks" reflect the homeostatic nature of the motivations. The level of "liquid" in a tank indicates the degree to which a need is satisfied; the lower the liquid level, the stronger the need.

Signals of affiliation (friendliness, a smile, body contact, approval, etc.) fill the affiliation–tank, whereas disapproval, an angry face or aggression, empty this tank. Signals of certainty are for instance a prediction that turns out to be true or a confirmation for a hypothesis. An unexpected event is a signal of uncertainty. Signals of efficiency indicate successes of all kind, even successes which are not related to the actual task; for instance, shouting at another person and eliciting a fearful and quiet reaction could be interpreted as success by the shouter. Signals of inefficiency are failures of all kind; therefore, signals of uncertainty and anti-affiliation signals are signals of inefficiency, too.

To stay in the metaphor, the parameters related to the competence tank modulate behavior. If the competence tank is leaking, arousal will rise. In other words, if a participant gets the impression that his or her competence of solving the task is lower than initially conceived, arousal will rise. The arousal's function is to create a general preparedness to act by raising the muscle tonus and by raising the readiness of the sense organs and the activity of the heart-lung-system. Additionally, through the suppression system some motives become the guiding motives and others are suppressed; this means a high degree of concentration on motives which could serve the purpose to raise competence.

The prediction of not handling a situation successfully is reflected in a low level of the competence tank. Low competence will lead to failures because of inadequate situation-related knowledge and skills. Low competence will also lead to low assessment of one's own abilities via self-reflection. Low competence will also produce cautiousness and hesitation.

Additionally, arousal will produce cortical inhibition which will result in quick decision making (Sohn et al., 2015). As another consequence of cortical inhibition all cognitive processes, which are necessary for decision making, remembering, exploration, planning, considering side- and long-term effects, will be rough and superficial. Hence cortical inhibition may result in impulsive behaviour and in disregarding harmful side- and long-term effects (Herman, Critchley, & Duka, 2018; Zermatten, Van der Linden, d'Acremont, Jermann, & Bechara, 2005). This is the price for making decisions quickly. Thus, when inhibition is high – such as during anger – the resolution level is low, and only the strongest connections in the memory network are activated.

Additionally, if the feeling of competence is decreasing and - to stay in the metaphor – the competence tank is leaking, there are tendencies to alter its level and to increase competence. Fig. 4 shows in the upper part some important action tendencies which could serve the purpose to raise the level of the competence tank or to preserve the level from further decline; in other words, actions that would increase the feeling of competence or actions that inhibit a further decline in the feeling of

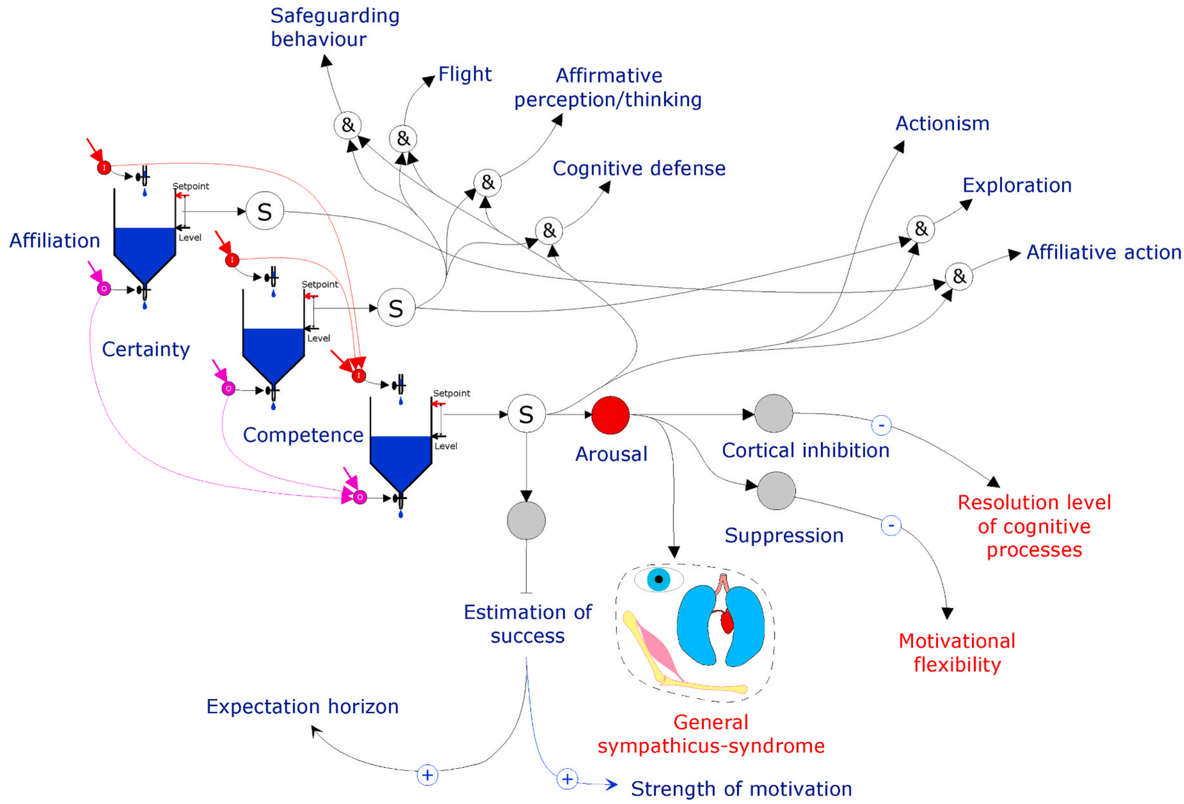

Fig. 4. Competence preservation and resulting errors.

competence.

1. **Safeguarding behavior**: This means a more or less frequent perceptual control of the environment to detect unexpected events over time. A too frequent control could nearly completely hinder any other cognitive activities. – Examples for this action tendency are Error 3.1. on entrenchment when participants engage in a too detailed and too long-lasting analysis of the situation, and Error 5.3. on avoiding making decisions because participants want to understand first the whole situation.
2. **Flight**: This means leaving a threatening domain of reality. Flight may hinder any activities to tackle the present problem. The problem seems to "disappear", unfortunately not really. – An example for this action tendency is Error 5.4. on overplanning and horizontal flight when participants flee into a controllable domain and attempt to develop detailed plans for this domain.
3. **Affirmative thinking or perception**: Only this kind of information is perceived and handled which is in accordance with the actual weltanschauung. Everything else is not seen; therefore, a too optimistic view of reality will be generated. – An example for this action tendency is Error 1.2. on overgeneralization of a successful plan because participants only considered information that they wanted to consider and that was similar to the previous situation.
4. **Cognitive defense (perceptual defense and thinking defense)**: Information which is not in accordance with the actual weltanschauung is actively blocked or denied or declared as a lie or a misperception. – Examples for this action tendency are Error 1.1. on denial of reality, when people avoid identifying difficult problems so that the current strategy does not need to be changed, and Error 3.3. on perceptual defense in teams when the team is in denial of the conflicting information.
5. **Actionism**: The purpose is to do something and to demonstrate competence, not so much to solve a problem. – An example for this action tendency is Errors 5.5. on underplanning and actionism, when the team does not engage in a discussion about goals, strategies, or detailed information collection, but instead makes decisions right away.
6. **Exploration**: Exploration means to admit ignorance and the need to gather further information regarding a domain of reality. Exploration is not very probable with people who feel incompetent. Additionally, a strong tendency for affirmative perception/thought might give the exploration a specific direction, i.e. to explore only in a potentially affirmative direction. – Examples for this action tendency are Errors 1.3. on status-quo thinking, when participants do not think far into the future and do not consider important time developments; and Error 4.2. on lack of analysis of problem causes.
7. **Affiliative action**: Any action to ensure help from a group or acceptance and acknowledgement. – An example for this action tendency is Error 5.7. on group harmony determining team decisions, when for the sake of peace in a team, opinions potentially contradicting the majority opinion are not voiced.

All these action tendencies may help (sometimes only for a short time) to strengthen the feeling of competence. But in the long run they are very dangerous. They suggest at first that one is doing something which is somehow related to solving a problem. All these tendencies, however, are not really constructive and in most cases exacerbate the problem situation even more. The problem solvers and decision makers are not aware of this in the actual moment as these actions will produce immediate relief. Exactly this feeling of relief is more important for the actors than the long-term effects of these actions. Thus, according to PSI-theory, the errors discussed are related to the human motivational and emotional system. Errors are not really errors, but they have a purpose. They bring about emotional stability and reduce stress in the current situation.

4.2. Explaining human error: plato

Our view that motivations and emotions can "cloud" cognitive processes can already be found in Plato's work. Plato (Timaeus, 69d) stated that the "pure intellect" is disturbed by four factors: rashness, fear, anger, and hope ("rashness[1] and fear, foolish counsellors both and anger, hard to dissuade; and hope, ready to seduce", Plato, 1925).

Plato refers to audacity/boldness and fear as foolish advisors, to anger that can hardly be appeased, and to hope that misleads. These adjectives are important. It is not audacity/boldness that should be avoided, but rather imprudent audacity/boldness. Hope is not to blame, but rather hope that is misleading and seducing – for example, the kind of hope one nourishes when ignoring or overlooking symptoms of a crisis.

These four emotions can be translated into information processing terminology. Foolish audacity/boldness means one overestimates the likelihood of success for courses of action (e.g., in methodical rigidity, Error 3.5.1.). Foolish fear is the contrary and refers to an underestimation of the likelihood of success for courses of action (e.g., in entrenchement, Errror 3.3.1.). As a consequence, one does not dare to act. Anger hard to dissuade refers to a person being stuck in a negative emotion and in the related cognitive schemas (low resolution level of thinking, as for example in status-quo thinking, Error 1.3., and in lack of analysis of problem causes, Error 3.4.2.). Being stuck in the hate of a specific enemy would be one example, such as Bush's "Axis of Evil," Ahmadinesjad's Iran, or Kim Jong-un's North Korea. This anger and hate might lead to a complete cessation of communication with the political opponents. Hope ready to seduce involves affirmative perception of reality and overlooking signs of failure, both confirming a worldview reflecting the world one wishes to see (e.g., in overgeneralisation, Error 3.1.2.). One continues with an action sequence, even if first signs of failure can be observed, because one still believes everything will turn out all right.

These factors (over- or under-estimation of the likelihood of success, being stuck in negative emotions and the related low resolution-level of thinking, and affirmative perception of reality and methodical rigidity) lead intelligent people to commit foolish errors. Intelligence is a necessary prerequisite for human error (see also, Sternberg, 2004). Only intelligent people who behaved intelligently in the past can be triggered by different situational demands and misperceptions to commit errors. Foolishness means striving for immediate success while at the same time reducing or jeopardising the long-term success.

Plato did not develop this list as a gut reaction. He observed the political events of his time: the Peloponnesian war, and the Thirty Tyrants in Athens. As a result of his analyses, he recommended a specific education for politicians so that they could avoid such foolish actions and so that politics could become a rational enterprise of justice (see Plato's Politeia, translated by Bloom, 1968). In his view, politicians should become "philosophers", friends of wisdom. This does not mean that politicians should become professors of philosophy, but they should become aware of their own thinking, realize the causes for their thinking, and come up with several solution alternatives to problems. Wisdom would mean to act adequately in a given situation. The errors we have discussed are related to thinking that is not adequate in a given situation.

5. Conclusion

The goal of the current study was to describe human error in complex, uncertain, and dynamic microworld situations according to the steps of complex problem solving and dynamic decision making, and to provide a theoretical explanation for those errors. We used three different microworlds, CHOCO FINE, MORO, and WINFIRE, with different characteristics, to get a wide variation of behavior. We then described 24 errors in detail, justified why they were errors, and discussed the causes of these errors. Our main finding is that the main causes of these errors are not cognitive limitations but are motivational and emotional processes – a view neglected in current cognitive and human factor approaches to human error.

Some of the errors are also discussed in other research, for example, methodical rigidity (see Reason, 1989), the influence of time pressure on behavior, goals, and increasing error (Beck & Schmidt, 2013; Van Hiel & Mervielde, 2007), the low resolution level of situation perception (attention lapses; Cheyne, Carriere, Solman, & Smilek, 2011; Madore et al., 2020), or errors in situation awareness (Endsley, 2020; Jones & Endsley, 2000), errors related to affirmative thinking and cognitive defense (e.g., reinvestment of resources in a losing course of action; Schultze, Pfeiffer, & Schulz-Hardt, 2012), or inaccurate perception (e.g., problem sensitivity; Buffardi, Fleishman, Morath, & McCarthy, 2000).

The list of 24 errors can be used in future studies. One could further operationalize these errors for a specific situation or microworld. One could analyze errors with at least four different methods: first, extracting errors from automatically saved log files showing events and decisions over time; second, extracting errors from videos of participants working on microworlds and/or videos of the computer screens using a coding system; third, extracting errors from recorded think-aloud protocols of participants while working on the microworlds (Güss, 2018); fourth, analyzing errors from post-hoc interviews after participants completed working on microworlds. Measuring the errors could be accomplished by using a coding system, specifying the errors, and then tallying the frequencies of errors over time. Researchers could then compare these errors among different groups of participants and among different simulations with different characteristics.

We provided a theoretical explanation referring to Plato and PSI-theory (e.g., Dörner, 1999) and the interrelatedness of cognition, motivation, and emotion. Other recent research has also shown this interrelatedness, for example, the "overlap" between self-reported everyday mistakes and the construct "self-evaluation of one's general worth and functioning" (in our term, competence; van Doorn, Lang, & Weijters, 2010). The theory described in the discussion section could be tested in further studies. As Trafimow (2012, p. 492) stated, "theories have non-observational terms with definitions that cannot be explicitly stated that are connected to observational terms used in data collection by auxiliary assumptions. Each auxiliary assumption contains at least one non-observational term, one observational term, and the relation between them." Thus, specific hypotheses have to be developed; competence, uncertainty, and affiliation as non-observational terms as well as specific errors have to be operationalized and assessed.

In this manuscript we have also specified predictions about how motivational and physiological parameter constellations can explain certain action tendencies. Future research could use self-report, neuropsychological and physiological measures to test some of our postulated assumptions about arousal, heart rate, cortical inhibition, competence, and decision making. Additionally, future research could also further investigate these errors in real-world contexts further investigating the external validity and generalizability. Future research could also investigate individual or situational differences regarding the 24 errors, for example comparing novices and experts or comparing the frequency of errors shown in different situations with different characteristics and relate these errors to performance. Güss, Tuason, and Orduña (2015), for example, assessed strategies and errors in the WINFIRE simulation and showed that errors decreased over time and that errors predicted performance and failure. Future research could also investigate if learning about these errors would lead to fewer errors and better performance in a computer-simulated problem task.

Something similar has been done in the research field on critical

[1] Although most English translations use the word "rashness," we believe the word "audacity/boldness" is closer to the original Greek word "θάρρος." In the famous Schleiermacher translation, you will find "Kühnheit" (audacity). Therefore we will use "audacity/boldness" in our further discussion.

thinking instruction in dynamic and complex situations (e.g., Sterman, 2000; or leaders' adaptability; Hannah, Balthazard, Waldman, Jennings, & Thatcher, 2013). Several studies have trained participants in critical thinking referring to four steps: situation analysis, search for conflicting or missing information, evaluation and search for alternatives, and judgment of whether a decision or more thinking is required (e.g., Helsdingen, van den Bosch, van Gog, & van Merriënboer, 2010) or training participants to self-reflect during dynamic decision making (Donovan et al., 2015). Compared to control groups, the critical thinking groups in the first study and the self-reflecting group in the second study have shown fewer errors and performed better. In a recent study, participants working on either the WinFire or the ChocoFine simulation were either given a brief training explaining a list of errors we discussed in this paper or they were not given such a training. Findings showed that performance was better in both simulations in the training group compared to the control group (Hermida & Güss, under review).

A limitation of the current framework is that we did not focus in detail on social-organizational causes for errors, such as hierarchies, work context, or culture (see, e.g., Güss & Dörner, 2011; Hagemann & Kluge, 2017; Hofinger, Rek, & Strohschneider, 2006; Hofmann & Frese, 2011; O'Neil, & Perez, 2008; Stempfle & Badke-Schaub, 2002; Strohschneider & Heimann, 2009; Wilson, Salas, Priest, & Andrews, 2007).

Investing time and money to analyze own errors – individually or as a company – also pays off. A McKinsey study of more than 1000 major business investments showed that when decision makers attempted to reduce the effects of errors and decision-making biases, they achieved returns up to 7% higher (Lovallo & Sibony, 2010). A study conducted in Switzerland with 129 top managers and CEOs revealed that more than 70% see the enormous potential of behavioral economic principles including error analysis for their companies and estimate and increase in sales by 13% and profit by 9% if used appropriately (Ackermann et al., 2020). Underlying behavioral economics is the viewpoint that - contrary to the classic view of a decision maker who is driven by rational expected utility models to maximize profit – employees and clients are people whose flaws, needs, and emotions primarily drive their decision making. A Gallup study revealed that "10 companies that applied these principles outperformed peers by 85% in sales growth and more than 25% in gross margin during a recent one-year period" (Fleming & Harter, 2012, p. 1).

Providing error lists in training programs can be dangerous, however, as they are only partially right. "Search for missing information" or the error we mentioned "Methodical rigidity" are sometimes errors and sometimes not. It depends on the situation. So, more importantly than providing specific lists of errors, is it to train participants to become aware of their own reactions, their own feelings, their own thinking in problem situations asking themselves for example, "What is wrong with me?" or "Why am I doing this?" Such self-reflection might help people become aware of their own emotions and motivations and of the causes of their thoughts and actions. They might realize, for example, that a certain decision they are about to make is caused by anger or is only a pure demonstration of power (to protect one's competence), rather than based on a rational analysis of the situational demands. Thus, one should check if one's thoughts and actions are based on high uncertainty and low competence. If the main purpose of a specific action is to protect one's competence, then caution is required. Most of the errors we mentioned in this paper could be avoided if people would invest some time for thinking about the reasons why they think in a specific direction and if people would be willing to change their thoughts and actions.

Declarations of interest

None.

Authors note

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CRediT authorship contribution statement

Dietrich Dörner: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization, Writing – review & editing. **C. Dominik Güss:** Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

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