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The Influence of Emotion and Emotion Regulation on Complex Problem-Solving Performance

C. Dominik Güss [1,†] and Ulrike Starker [2,*,†]

1 Department of Psychology, University of North Florida, Jacksonville, FL 32224, USA; dguess@unf.edu
2 Faculty of Business Studies, Harz University of Applied Sciences, 38855 Wernigerode, Germany
* Correspondence: ustarker@hs-harz.de; Tel.: +49-3943-659-212
† These authors contributed equally to this work.

Abstract: Complex problem solving (CPS) research has focused on cognitive variables, but in recent years, the influential role of emotions and motivation during the CPS process has been highlighted. In the current study, we focus on emotion regulation during CPS. Eighty-three university students worked on a simulated chocolate-producing company. Initially, they completed a survey on emotion regulation and demographics. Then, they were randomly assigned to four conditions where emotions were induced with short video clips: anger, fear, happiness, and trust. A manipulation check assessed the successful priming of emotions. While working individually on the microworld, CPS behavior and performance were saved in log files. We hypothesized that happiness and trust would lead to better performance than fear and anger. We also hypothesized that emotion regulation would be positively related to performance. There were no differences in performance at the beginning and at the end of the simulation among the four emotion groups. Regression analyses showed that emotion-regulation strategies significantly predicted CPS performance. Aggression was positively related to performance. Results show that it is more the regulation of emotions than the emotion per se that influences CPS performance.

Keywords: emotion regulation; emotion; complex problem solving; dynamic decision making; microworld; stress

1. Introduction

Solving complex problems is a key challenge not only for individuals in their private lives but also in their professional lives, and for societies as a whole. Complex problem solving (CPS) refers to solving problems that are complex, dynamic, and non-transparent [1–3]; they consist of many interwoven variables; they change over time independently of the decisions people make; and not all aspects are known to the problem solver and decision maker. Similarly, many researchers in the field of business speak of VUCA-world problems, problems in a business environment that are volatile, uncertain, complex, and ambiguous [4,5]. Given the characteristics of problems in real life, rather than relying on simple and static tasks or riddles that have been used in the field of problem-solving research for a long time, it is advantageous to study problem solving in such complex, dynamic, and non-transparent tasks. In most cases, microworlds or computer-based learning environments have been used to study CPS.

Whereas past research has focused mainly on the cognitive processes involved in CPS, newer research discusses the need to focus on the interaction of motivation, emotion, and cognition [6–8]. In their definition of CPS, Dörner and Funke [3] specifically state, "The problem-solving process combines cognitive, emotional, and motivational aspects, particularly in high-stakes situations". Yet, empirical research on CPS has rarely investigated the role of emotions on the problem-solving process. Also, problem-solving research in specific fields such as physics and engineering has often neglected the role of emotions

in in-the-moment reasoning [9,10]. Although the role of emotion in making choices and decisions has traditionally played a minor role in research, it has become more influential in recent years [11]. Yet, many newer studies investigating emotion, motivation, and cognition have been correlational in nature, limiting the conclusions that can be derived [12].

Emotions represent specific qualities of a needs-regulating system, including specific action tendencies, typical information processing patterns, and characteristic physiological configurations [13,14]. From an evolutionary perspective, emotions are quick information processing systems that help people act with minimal conscious deliberation [15].

In one study, Spering, Wagener, and Funke [16] induced positive and negative emotions by providing wrong feedback to participants. Before working on a computer-simulated task, participants worked first on a spatial reasoning test and were then randomly assigned to one of three conditions: positive feedback—false high score was provided, negative feedback—false low score was provided, and control—no feedback. These conditions did not lead to differences in performance, but to differences in CPS behavior, such as more information search for the negative emotion group. In another study with medical students working on a computer-based learning environment, participants with positive emotions showed the highest performance compared to participants in the negative emotion cluster and participants in the low-intensity emotion cluster [17].

Could it be that emotions are not just a hindrance for rational problem solving but that they are, in fact, facilitating successful CPS? What are characteristics of successful CPS? Research concerning successful CPS has shown mixed findings. Studies investigating CPS and the relationship with wisdom [18], intelligence [19–21], personality [22], "savants" [23], creativity [24], culture [25], and general strategic knowledge [26,27] couldn't predict successful CPS adequately. Only domain-specific knowledge was related to CPS performance in some instances [28], problem-solving strategies [19,29,30], as well as self-consciousness and self-reflection to some degree [31,32].

What is it that makes a problem solver successful? Perhaps a closer look at the dynamics of CPS and related errors can help shed some light on this question and show the importance of emotion regulation.

1.1. Competence Regulation

Research on human error and cognitive biases has shown that one key cause is overconfidence [33] and the protection of one's feeling of competence [34]. The competence need is a central human need that indicates the extent to which someone feels capable or incapable of solving problems and dealing with the environment successfully [7,35]. The need is satisfied if someone is able to solve a problem and change the environment effectively; the need arises if someone feels incapable of coping with a specific problem and unable to change the environment effectively. In most cases, a strong need of competence is accompanied by strong negative emotions such as anger, frustration, or fear.

A situation that cannot be changed or that is experienced as overwhelming is also experienced as a threat. When it is unclear whether planned actions will have the intended consequences, then one often looks for controllable domains of reality in which at least some success can be achieved; for example, blaming others, solving unrelated issues, and denial are common errors in threatening situations [2].

Thus, human thought and behavior generally follow two goals: first, the specific goal related to a specific task, and second, the maintenance of the feeling of competence [7]; (see also research on self-efficacy, achievement and task performance [36,37]). Achieving these two goals together is relatively easy in regular daily life activities and in well-practiced domains. In complex, dynamic, and non-transparent problem situations, however, protecting one's feeling of competence can sometimes have priority over actually solving the specific problem, especially when one is under extreme time pressure, when the problem is of high interest, when not enough problem-related knowledge exists, or when one's face has to be saved in a group [38,39].

1.2. The Connection between Cognition and Emotion following PSI-Theory

Errors in complex, dynamic, and non-transparent situations are related to certain emotions. To explain the interrelatedness of emotions and CPS, we will refer to PSI-theory, a theory that explains the interaction of motivation, emotion, and cognition [7,40]. In PSI-theory, the competence need (as just described) and the certainty need play a central role. The certainty need refers to the predictability of the course of events and the effects of one's own actions [35].

The main assumption is that emotions are a result of mainly five internal parameter constellations and behavior tendencies. These five parameters are resolution level, selection threshold, activation, competence need, and certainty need (see Table 1) [35]. As we will demonstrate, these parameters show how motivational, emotional, and cognitive processes are interconnected.

Table 1. Emotions and Their Characterizations Through the Modulation Parameters. Advantages and Disadvantages of the Four Emotions in Relation to CPS.

Emotion	Parameters					Cognitive Style	
	Resolution Level	Selection Threshold	Activation	Competence Need	Certainty Need	Advantage	Disadvantage
Anger	low	high	high	medium	medium	Active, ready for action	Overdosage, forgetting side effects
Fear	low	low	medium	low	low	Passive, reacting careful	Encapsulation, ballistic planning and methodism
Trust	low	low	low	high	high	Developing strategies	Too little criticism
Happiness	medium	medium	medium	high	high	Creative thinking	Little self-reflection

The resolution level refers to the depth and width of associations in long-term memory. If the resolution level is deep and wide, then it encompasses many memory elements to use during planning and problem solving. If the resolution level is shallow and narrow, then only little memory content is activated. Neither resolution level is necessarily better nor worse than the other, but instead may be better suited in differing situations. In a dangerous situation, a shallow and narrow resolution level leads to quick scanning of the environment and quick memory search, allowing quick action [41].

The selection threshold refers to the degree of inhibiting non-guiding motives when one motive is active. To be more specific, the selection threshold puts weights on other motives. If the selection threshold is high, one is focused solely on one motive and on achieving one goal (for empirical evidence, see also research on task-switching and inhibition [42]. If the selection threshold is low, one oscillates between motives and is easily distracted. Similar to the case of resolution levels, the selection threshold value varies situationally. Multitasking occurs when the selection threshold is low and can be detrimental in CPS (e.g., in military tasks [43] and problem-solving tasks [12]).

The last parameter is activation. Activation makes the body and mind ready for action [44,45]. Activation influences resolution level and selection threshold. Activation increases when competence decreases. When activation rises and is very high—as in a dangerous situation, for example—the resolution level of perception and thinking is very low. When activation is high, then the selection threshold is high, which means one is solely focused on one motive.

Emotions can be characterized as a specific constellation of the competence and certainty needs, the three parameters, and certain behavior tendencies. Fear, for example, can be characterized by low competence and low certainty, resulting in the behavior tendency flight. Fear is additionally characterized by low resolution level, i.e., perception is superficial, and thoughts wander quickly; low selection threshold, i.e., one is easily distracted and oscillating between motives; and medium activation, i.e., one feels tense.

Related to solving complex problems, fear can lead to second-guessing oneself, ruminating, delaying, and avoiding making decisions.

Anger occurs, for example, when someone cannot reach an important goal or loses a game. Anger can be characterized by a very low-resolution level, i.e., perception is superficial and thoughts wander quickly; high selection threshold, i.e., one is solely focused on one motive; and high activation, i.e., one is highly aroused and ready for action. Anger is also characterized by medium competence and low certainty, resulting in the behavior tendency quick action and perhaps aggression. Which specific action tendency is selected also depends on previously acquired knowledge on how to deal with problem situations. Related to solving complex problems, anger can lead to superficial thinking, a lack of problem analysis, a lack of planning, a focus on only one problem aspect instead of several, and quick decision making. Thus, emotions can be described through the modulation parameters and behavior tendencies and are connected to specific thought processes.

Empirical studies support some of the thought tendencies related to certain emotions we just discussed. Experiencing anger is related to making more mistakes [46]. Positive feelings are related to more creative thinking [47] and better performance in a variety of cognitive tasks [48]—also to better performance in complex real-world domains [49,50]. As a meta-analysis on emotions and creativity has shown, positive emotions are related to more fluency of thinking [51]. Negative emotions narrow thought–action repertoires and resolution level of thinking [52]. Regarding fear and the related low-resolution level, findings showed more heuristic processing and less systematic processing [53].

To solve complex and dynamic problems, it is important to adapt to the challenging situation and control one's emotion. Trust is important as it can provide the necessary confidence and optimism to solve a problem successfully. Rousseau, Sitkin, Burt, and Camerer [54] (p. 395) define trust as a "psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another." Thus, trust refers to positive expectations one has regarding another person, the "willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party." [55] (p. 712). Additional components of trust are mentioned by [56], who summarizes the four components that can be found in the literature on trust: risk, reciprocity, time, and area specificity.

Table 1 shows four selected emotions for the current study (anger, fear, trust, and happiness) and their respective parameter constellations. Emotion researchers often distinguish six basic emotions (anger, sadness, happiness, disgust, fear, and surprise). We included three of those (anger, happiness, and fear) in our study. We did not include surprise and disgust as they are often very situation-specific and difficult to relate to CPS. We did not include sadness because it was not related to CPS in other studies [14]. We decided to include trust as it is an important emotion in the educational context and social relationships, and some emotion researchers include trust as a basic emotion [57]; see also eight basic emotions: anger, anticipation, joy, trust, fear, surprise, sadness, and disgust [58]. The table also shows the advantages and disadvantages of these emotions in relation to problem solving and decision making. Not one emotion, per se, is "better" than another. It depends on the situation.

1.3. Emotion Regulation and CPS Performance

What effect does emotion regulation have on CPS? Although the four emotions described trigger specific thoughts and behavior tendencies, and although some are more conducive in the specific problem situation we selected for the current study, an alternative hypothesis could be that, during the CPS process, a wide variety of cognitive processes and different behaviors are demanded. Thus, it is not so much one tendency related to one emotion that is beneficial but rather the adjustment of different emotions during different parts of the long problem-solving process [14]. Research on emotional intelligence [59] and emotion regulation [60,61] has advocated for this position and shown empirical evidence

for the importance of emotion regulation. Recognizing and managing one's own emotions is especially important during the CPS process and the related demands of information overload, non-transparency, change, and stress. Studies on decision making using simple tasks have shown that the reappraisal of emotions can be helpful and effective [62]. In this sense, emotions can provide a first intuitive overall impression of the situation and trigger certain cognitive tendencies that can be followed or not. If, for example, anger is experienced and one is prone to make quick decisions focusing on one problem aspect only, then emotion regulation can help in recognizing anger and modifying the related behavior tendencies. One can then, for example, take a step back and instruct oneself to analyze the situation before jumping to quick decisions. Following this argument, emotion regulation helps modulate emotions and cognitive style, thereby improving problem solving. Therefore, emotion regulation should be positively related to CPS performance [14]. This is, to our knowledge, the first study investigating the role of emotion regulation in a complex, dynamic, and uncertain computer-simulated task.

The hypotheses of the current study are:

- Regarding the effect of specific emotions, it is expected that trust and happiness will be more conducive to CPS performance than anger and fear.
- Emotion regulation is positively related to CPS performance.

2. Materials and Methods

2.1. Participants

The participants were 89 students at a University in the Southeast of the United States. 75.3% of all participants were female, and 24.7% were male. Participant ages ranged from 18 to 41 years (M = 21.93, SD = 4.16). ChocoFine data of six participants were not saved due to computer problems or participants accidentally exiting the program. Data of six participants (and one for month 12) were excluded as they were extreme outliers, resulting in a total of 76 participants for the final month 12: 18 in the fear group, 21 in the happiness group, 17 in the anger group, and 20 in the trust group (see the section on emotion induction for more details on the four groups).

2.2. Instruments

2.2.1. ChocoFine

To assess CPS, we administered the computer-simulated microworld ChocoFine [63]. The advantages of microworlds to study problem solving and decision making have been widely discussed [64]. ChocoFine is the highly complex simulation of a chocolate company with more than 1000 simulated variables in 19 domains (e.g., personnel, marketing, and production).

Participants took the role of CEO and managed the company for 12 simulated months over the course of a 1.5-h session. Participants worked individually on the simulation. For each month, they gathered information and made decisions. Then, they moved to the next month, analyzed the changes that occurred, gathered information again, and then made their decisions.

The user interface of the program consists of 3 screens: the main screen, the production screen, and the marketing screen. The ChocoFine simulation is automatically set to run full screen. The main screen shows basic data and information, such as production, demand, sales, account balance, deliveries per day, stock of inventory, and open orders. The production screen shows the 6 machines, their capacities, and which chocolates they can produce. There, participants can directly enter the production numbers of specific chocolates for the month they are currently working on. Figure 1 shows the marketing screen with the city map and the districts in pie charts. The menu buttons on the right allow participants to gather specific information and make decisions related to, for example, advertising (e.g., general advertising for their company or specific advertising for specific chocolates), the design of their chocolates, prices (e.g., prices for ChocoFine chocolates and prices of competitors' chocolates), and the sales personnel (e.g., how many, or how many

in each district). When participants move from one month to another month, sometimes messages appear, reflecting changes in the market or related to their competitors. This allows participants to react to these changes. Performance was operationalized as total money at the end of each month. Capital at Month 12 was chosen as the performance variable for the correlational analyses.
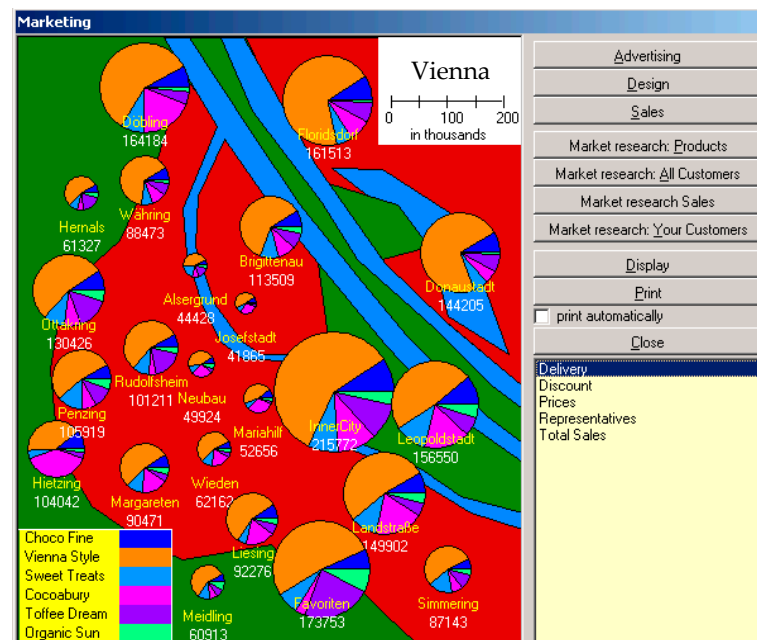

Figure 1. Marketing screen of the ChocoFine simulation showing the different market segments of the competitors in the city of Vienna and the menu options at the right regarding advertising, design, sales, and market research.

2.2.2. Emotional Adaptation during Problem Solving (EAPS)

Why did we specifically select this instrument to assess emotion regulation in CPS? We searched for an instrument that (a) assesses several different emotion-regulation tendencies, (b) assesses emotion-regulation related to stress and complex problem situations, and (c) is related to some of the constructs/parameters we discussed before. For example, boost in self-confidence is directly related to the concept of competence. Flight tendency is related to low competence and high uncertainty. Resignation is related to being overwhelmed and not knowing solutions to the current problems. Aggression is related to anger, as we discussed previously, i.e., very low-resolution level, high selection threshold, high activation, medium competence, and low certainty.

We created a survey to assess Emotional Adaptation During Problem Solving (EAPS) based on 6 of the 20 subscales of the coping with stress scale [65]. Each of the six subscales has five Likert scale items (from 1-not at all to 5-very likely). Each item completes the introductory sentence: "If I am in a difficult situation which affects me emotionally, then ... "

1. Positive reframing of the situation: Cronbach's alpha = 0.66 (M = 3.53, SD = 0.61, N = 89), sample item: " ... I tell myself it will all be okay again."
2. Self-reflection and monitoring: Cronbach's alpha = 0.61 (M = 4.06, SD = 0.53, N = 89), sample item: " ... I try to think of the possible consequences my actions might have."
3. Boost of self-confidence: Cronbach's alpha = 0.78 (M = 3.85, SD = 0.64, N = 89), sample item: " ... I tell myself I can stick it out."
4. Flight tendency: Cronbach's alpha = 0.76 (M = 2.75, SD = 0.71, N = 89), sample item: " ... I get out of the situation as quickly as possible."
5. Resignation: Cronbach's alpha = 0.73 (M = 2.12, SD = 0.64, N = 89), sample item: " ... I tend to give up easily."

6. Aggression: Cronbach's alpha = 0.73 (*M* = 2.32, *SD* = 0.63, *N* = 89), sample item: " . . . I take my anger out on other people."

Reliabilities would not improve if specific items were to be deleted from the subscales. The range of reliabilities from 0.61 to 0.78 is acceptable and good, considering the scales each have 5 items only [66]. Cronbach's alpha values tend "to underestimate the internal consistency of scales consisting of fewer than 10 items." [67] (p. 8). It is noteworthy that the means for the first three more positive emotional adaptation subscales are higher than the means of the three more negative subscales.

Confirmatory Factor Analyses for each of the six subscales were conducted (see Table 2) using Robust Maximum Likelihood estimation in the program R-Studio with the package lavaan. To determine if a subscale showed "poor", "marginal", or "good" fit, we focused on the χ^2 fit index, the CFI, and TLI (smaller 0.90 means poor fit, greater 0.90 means marginal fit, and greater than 0.95 means good fit) [68,69], RMSEA (greater than 0.08 means poor fit, smaller than 0.08 means marginal fit, and smaller than 0.05 means good fit) [70], and the SRMR (greater than 0.10 means poor fit, smaller than 0.10 means marginal fit, and smaller than 0.08 means good fit) [71].

Table 2. Results of Confirmatory Factor Analyses for the Six Subscales of the Emotional Adaptation During Problem Solving Scale (EAPS) and Overall.

	χ^2	*df*	χ^2/*df*	*p*	CFI	TLI	RMSEA	SRMR	Standard Loadings *p*s <
Positive Reframing	6.01	5	1.20	0.31	0.99	0.97	0.05	0.05	0.02
Self-Reflection	4.73	5	0.95	0.45	1.00	1.00	0.00	0.04	0.01
Boost of Self-Confidence	9.82	5	1.96	0.08	0.96	0.92	0.10	0.04	0.001
Flight Tendency	3.47	5	0.69	0.63	1.00	1.03	0.00	0.03	0.001
Resignation	9.65	5	1.93	0.09	0.95	0.91	0.10	0.05	0.01
Aggression	5.93	5	1.19	0.31	0.99	0.98	0.05	0.04	0.01
6 subscales	616.97	390	1.58	0.00	0.71	0.68	0.08	0.10	0.02

All χ^2 were not significant, and all χ^2/*df* ratios were $\leq$2, which indicates superior fit between the hypothesized model and the sample data [69]. Considering CFI and TLI together, all six subscales showed good fit with values over 0.95, except for the Boost of Self-Confidence and Resignation scales. Regarding RMSEA, three subscales showed good fit, while the Boost of Self-Confidence and Resignation subscales showed poor fit. However, the RMSEA is not a good criterion for small degrees of freedom and small sample sizes [72]. Regarding SRMR values, all six subscales showed good fit.

Looking at all five fit indices together, the results for the four subscales, Positive Reframing, Self-Reflection, Flight Tendency, and Aggression, show good fit. The fit indices for Boost of Self-Confidence and Resignation show marginal to good fit. The results for the Confirmatory Factor Analysis for all six subscales together showed bad fit. This is not surprising since, theoretically, we assume the six factors to be relatively independent since the overall sample size of 89 was too small to test the overall model.

2.2.3. Demographic Survey

Additionally, participants were asked to provide demographic information such as gender, age, major, GPA, ethnicity, socio-economic status, hours playing video games per week, employment experience, and previous experience with ChocoFine. None of the demographic variables correlated significantly with ChocoFine performance in month 12 (*p*s > 0.39). None of the participants had worked on the ChocoFine simulation before.

2.2.4. Emotion Induction

Participants watched one of four videos intended to induce specific emotions. Each video lasted between 1:44 and 3:50 min. Video 1 showed young dogs and cats and their clumsy behavior and was supposed to elicit happiness. Video 2 showed the trailer to A

Quiet Place, a horror movie, and was supposed to elicit fear. Video 3 showed a short investigative report on companies pretending to collect donations for cancer research and cancer patients but showing that most of the money goes to the company owners' salaries. This video was supposed to elicit anger. Video 4 showed citizens of a small city who installed donation boxes around their town. People of the city leave canned goods and other items in these places, and those citizens in need can then get the items they need. This video was supposed to induce trust. The four emotion groups did not differ regarding gender, $\chi^2(3) = 1.51$, $p = 0.68$; GPA, $F(3, 76) = 0.447$, $p = 0.72$; nor age, $F(3, 83) = 2.716$, $p = 0.05$. Tukey HSD tests did not show any significant differences among the four emotion groups regarding age (all $ps > 0.06$).

As a manipulation check, we asked participants after the video to indicate which of the following four emotions they currently experience, "Which emotion do you feel right now? Please encircle: Anger, Happiness, Trust, or Fear." Results showed that 84.0% of the participants presented with the "happiness" video experienced happiness, 60.0% of the participants presented with the "fear" video experienced fear (6 of the 20 participants in the fear condition showed happiness, probably those who like horror movies), 90.5% of the participants presented with the "anger" video experienced anger, and 28.6% of the participants presented with the "trust" video experienced trust (14 of the 21 participants in the trust condition showed happiness). Earlier studies [14,46,48] showed that such short videos can induce emotions for about two hours. As the results of the manipulation check show problems with inducing trust, we run statistical analyses for both the hypothesized emotion groups and then again with the self-reported emotion groups.

2.3. Procedure

The experiment was announced on an online platform for students, which shows all the experiments currently conducted in the psychology department. Students could come at certain specified times to a computer lab with 40 available computers for a period of 2 h. There was always a maximum of 15 spots available. The number of participants per session varied between 3 and 12. Never did participants sit next to each other or directly behind each other during the experiment. Each group was randomly assigned to one of the four emotion conditions. Each group watched together one of the four emotion videos projected with the classroom projector on the big classroom screen. Thus, every participant in the same group watched the same emotion video.

First, student participants read and signed the Informed Consent form. We did not use deception but informed participants upfront in the Informed Consent Form about the purpose of the study: "The purpose of the study is to investigate the role of emotions when people deal with the complex Choco-Fine simulation ... " The study was approved by the Institutional Review Board #1195676-2. Students then logged on to Qualtrics to answer the questions of the EAPS. Then, they answered the demographic questions.

Participants were then provided a 3-page printed introduction for the ChocoFine simulation they kept for the duration of the whole experiment. The sheet explained the three simulation screens and the menu options, including commands of ChocoFine. After participants read the instructions, they started the training simulation. The experimenter explained again the screens, data shown, and the menu and command options. Then participants had 10 min to click on various menu buttons and explore the simulation. Next, the ChocoFine simulation was switched off. Now all the students in the lab watched one of the four videos inducing a specific emotion. Then students indicated on a small piece of paper, which also included their participant code, which of the four emotions they were currently experiencing. All students restarted the ChocoFine simulation and worked in their role as CEO for 1.5 h for minimum 12 months of the simulation. These data were automatically saved in log files.

3. Results

3.1. Outliers, ANOVA, Multiple Regression Analyses

Before reporting the results and testing the two hypotheses, we have to address the issue of outliers. To do so, we created boxplots for the variable "capital" for months 1 to 12. Boxplot graphs showed five extreme outliers with capital less than −3.5 m. Two outliers were from the anger group (31 and 35), two outliers from the happiness group (4 and 7), and one outlier from the trust group (24). Then, we removed one outlier (happiness group, outlier 1, outperformed all other participants dramatically) and the outlier 72 (anger group, but only for month 12).

From a statistical point of view, they are outliers, and common research practice is to remove them from the data set. The "outliers", however, could have been caused by unreasonable decision making, which, in turn, could have been caused by the emotions induced by the experimental condition. The worst performance was shown by two students in the anger group and two students in the happiness group. Potentially, anger with related low-resolution level of thinking and happiness with a related lack of coordination and self-reflection could be detrimental to CPS.

At first, we included the outliers in the Krustal–Wallis test and the Median test. Due to the non-normal distribution of the performance data, we calculated the nonparametric Krustal–Wallis test to compare the performance means, i.e., the capital in several months in the four emotional conditions (anger, fear, happiness, and trust). All results were not significant, for month 1, $p = 0.64$; for month 2, $p = 0.99$; for month 3; $p = 0.97$; for month 11, $p = 0.42$; and for month 12, $p = 0.49$.

The median for total capital in month 12 for the anger group was 981,347.39, 822,524.05 for the happiness group, 917,949.11 for the trust group, and 1,048,739.02 for the fear group. Moreover, a Median test comparison of the medians in the four emotional conditions did not show significant differences for month 1, $p = 0.41$; for month 2, $p = 0.76$; for month 3; $p = 0.73$; for month 11, $p = 0.29$; and for month 12, $p = 0.29$.

Hypothesis 1 stated that trust and happiness would be more conducive to CPS performance than anger and fear. The anger and trust groups performed best. Comparing performance, i.e., capital in month 12, among the four emotional conditions, anger, fear, trust, and happiness—not including the seven extreme outliers—showed no significant differences among the four groups, $F(3, 72) = 1.734$, $p = 0.168$, $\eta^2_p = 0.067$, with medium effect size (Figure 2).
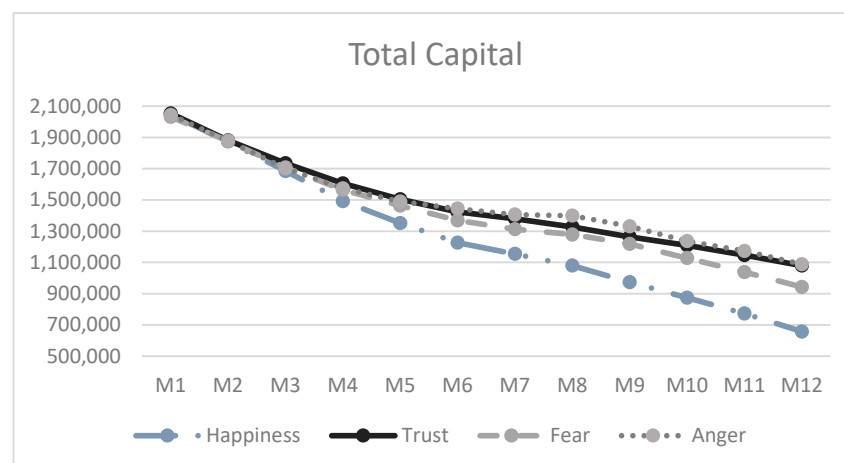

Figure 2. The means of total money in the first 12 months of the ChocoFine simulation for the four different emotion conditions.

It could be that the effect of emotion induction is stronger at the beginning of the simulation, right after watching the videos. Therefore, we compared capital in month 2 among

the four conditions, but the results were also not statistically significant, $F(3, 78) = 0.016$, $p = 0.997$, $\eta^2_p = 0.001$.

As mentioned in the method section, the manipulation check revealed some problems with inducing trust. We, therefore, conducted the same analyses regarding ChocoFine performance using the self-reported emotions. Participants selected the emotion they experienced, given trust, anger, happiness, or fear right after watching the short videos. Furthermore, these analyses did not reveal significant differences in performance in month 2, $F(3, 78) = 0.395$, $p = 0.757$, and in month 12, $F(3, 71) = 1.115$, $p = 0.349$.

Hypothesis 2 stated that emotion regulation is positively related to CPS performance. We, therefore, calculated Pearson correlation coefficients between performance in the first few months and at the end of the simulation in month 12 and the means of the six emotion-regulation EAPS subscales: Positive Reframing, Self-Reflection, Boost of Self-Confidence, Flight Tendency, Resignation, and Aggression.

Scores of the three subscales, Self-reflection, Boost of Self-Confidence, and Resignation, did not correlate significantly with performance at the beginning nor at the end of the simulation. Positive reframing was negatively correlated with performance in months 2 and 3. Positive reframing contains items such as "If I am in a difficult situation which affects me emotionally, then I tell myself, it is not so bad" or "If I am in a difficult situation which affects me emotionally, then I tell myself it will all be okay again." Since these are correlational data, it is unclear if positive reframing is a cause of low performance or is a consequence of low performance.

High flight tendency with items such as "If I am in a difficult situation which affects me emotionally, I tend to remove myself from the situation" or "If I am in a difficult situation which affects me emotionally, I only wish to get away" was marginally significantly negatively related to performance. Withdrawing from the situation was related to poorer performance.

Surprisingly, aggression was significantly positively related to performance. Sample items would be "If I am in a difficult situation which affects me emotionally, then I would like to throw something against the wall" or "If I am in a difficult situation which affects me emotionally, I become irritable." The higher the aggression score, the higher the performance.

A sample analysis in G*Power for a linear multiple regression analysis with nine predictors, a median effect size of Cohen's f^2 of 0.20, a power of 0.80, and alpha value of 0.05 shows a required sample size of 88 participants. The sample of the current study initially had 89 participants. We conducted a robust multiple linear regression analysis to predict CPS performance with the dummy-coded-induced emotions and the means of the six emotion-regulation strategies. Not relying on assumptions of normality or homoscedasticity is the main advantage of robust regression analysis with bootstrapping. Tolerance values below 0.1 or 0.2 and Variance Inflation Factors VIFs of 5, 10, or higher would indicate multicollinearity. Tolerance values in the regression analyses varied between 0.51 and 0.87, and VIF values varied between 1.15 and 1.98, both indicating no problems with multicollinearity. The overall model explained 22.4% in the CPS variance; $R^2 = 0.224$, $F(9, 66) = 2.122$, $p = 0.040$. The only significant predictor was high aggression (see Table 3 for descriptive statistics, Table 4 for Pearson correlations, and Table 5 for regression results). The robust model only including the four emotions explained 4.5% in the CPS variance; $R^2 = 0.067$, $F(3, 72) = 1.734$, $p = 0.168$. Only anger was a significant predictor ($\beta = 0.260$; $p = 0.043$). The robust model only including the six emotion-regulation strategies explained 16.6% in the CPS variance; $R^2 = 0.166$, $F(6, 69) = 2.296$, $p = 0.044$. Only aggression was a significant predictor ($\beta = 0.331$; $p = 0.003$).

Table 3. Descriptive Statistics for Performance in Months 2 and 12 for the Four Emotion Conditions.

	N (Month 2)	*M* (Month 2)	*SE* (Month 2)	*N* (Month 12)	*M* (Month 12)	*SE* (Month 12)
Happiness	22	1,876,062.933	21,027.648	21	657,792.993	160,957.374
Trust	21	1,878,840.495	26,221.427	20	1,079,186.764	159,558.005
Fear	19	1,877,767.049	19,678.204	18	942,989.560	154,603.449
Anger	20	1,882,428.308	15,248.234	17	1,088,282.596	145,432.230

Table 4. Pearson Correlations between the Six Emotion-Regulation Strategies and ChocoFine Performance.

	M1 Capital	M2 Capital	M3 Capital	M4 Capital	M12 Capital	PR	SR	BSC	FT	RE
Positive Reframing PR	−0.11	−0.27 *	−0.22 *	0.16	−0.15					
Self-Reflection SR	−0.02	−0.02	−0.06	−0.09	−0.06	0.29 **				
Boost of Self-Confidence BSC	−0.001	−0.11	−0.12	−0.11	−0.02	0.54 ***	0.47 ***			
Flight Tendency FT	−0.06	−0.03	0.01	−0.06	−0.20 †	0.05	−0.18 †	−0.21 *		
Resignation RE	0.07	0.13	0.14	0.13	−0.04	−0.10	−0.18 †	−0.40 ***	0.56 ***	
Aggression	0.05	0.05	0.12	0.16	0.26 *	0.01	−0.15	−0.14	0.27 **	0.34 ***

Note: † $p < 0.10$, * $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$. PR Positive Reframing, SR Self-Reflection, BSC Boost of Self-Confidence, FT Flight Tendency, RE Resignation, and Aggression.

Table 5. Robust Regressions of Associations between CPS Performance and Emotions and Emotion-Regulation Strategies.

Variable	*B*	*SE*	β	*t*	*p*	95% CI *LL*	95% CI *UL*
Constant	726,309.517	1,000,905.514		0.829	0.465	−1,233,947.304	2,659,315.897
Happiness	−373,265.224	211,033.074	−0.242	−1.699	0.091	−808,747.012	29,842.158
Anger	81,844.960	213,272.755	0.050	0.359	0.693	−327,355.570	513,822.774
Fear	−125,289.842	221,282.519	−0.077	−0.560	0.559	−526,202.904	335,912.749
Positive Reframing	−179,157.044	137,671.922	−0.147	−1.072	0.190	−466,440.601	84,303.680
Self-Reflection	24,852.300	181,314.435	0.019	0.146	0.892	−319,881.665	413,868.069
Boost of Self-Confidence	122,749.658	143,703.370	0.110	0.724	0.394	−158,202.933	391,485.057
Flight Tendency	−240,756.461	145,314.929	−0.249	−1.853	0.098	−574,019.724	27,264.356
Resignation	58,966.861	199,701.715	0.055	0.371	0.765	−274,624.120	512,837.743
Aggression	391,528.606	119,875.433	0.359	3.084	0.003	141,708.418	610,755.328

Notes. LL = lower limit, UL = upper limit. The three dummy-coded emotion groups, happiness, anger, and fear are compared to the fourth group trust.

3.2. Post hoc Analyses of CPS Behaviors

We also compared expenses for information (accessing information in ChocoFine costs money, similar to conducting market research in the real world) during the first two months and expenses for advertising during the first two months across the four emotion conditions. Potentially, the induced emotions lead to different information processing, showing the need for information and risk-taking in advertising. For advertising, three extreme outliers with expenses greater than USD 50,000 were removed, and for information-gathering expenses, one outlier with expenses greater than USD 50,000 was removed. No significant differences were found among the four conditions, $F_{\text{Advertising}}(3,77) = 1.12$, $p = 0.35$; $F_{\text{InfoGathering}}(3,79) = 0.57$, $p = 0.63$ (see Table 6 for descriptive statistics).

Pearson Correlations among advertising expenses and information expenses in the first two months and the six emotion-regulation strategies did not show any significant results (see Table 7).

Table 6. Descriptive Statistics for Advertising Expenses and Expenses for Information for the Four Emotion Groups.

		N	*M*	*SD*
Advertising expenses	Anger	18	2847.54	4839.04
	Happiness	23	2636.74	5120.81
	Trust	21	5413.61	7876.35
	Fear	19	2714.74	4490.03
	Total	81	3421.81	5800.35
Expenses for Information	Anger	20	6650.00	10,314.91
	Happiness	24	6583.33	8026.68
	Trust	21	7833.33	9539.83
	Fear	18	10,277.78	12,269.31
	Total	83	7716.87	9910.94

Table 7. Correlations among Advertising Expenses and Expenses for Information and the Six Emotion-Regulation Strategies.

	Advertising Expenses	**Information Expenses**
Information Expenses	0.13	
Positive Reframing	−0.01	0.10
Self-Reflection	−0.02	−0.01
Boost of Self-Confidence	−0.03	−0.06
Flight Tendency	−0.14	0.08
Resignation	−0.12	0.09
Aggression	0.05	0.02

4. Discussion

The main goal of this study was to investigate the role of emotions and emotion regulation during CPS. The first hypothesis stated that happiness and trust would be more conducive to CPS performance than fear and anger. The emotions were induced in the current study with short video clips before the start of the simulation. Comparing performance among the four emotion groups did not show significant differences in performance neither at the beginning nor at the end of the simulation (both using non-parametric statistics including outliers and parametric statistics excluding outliers). Comparing decision-making behaviors regarding advertising and information collection in post-hoc analyses in the first two months of ChocoFine did not reveal significant differences among the four emotion groups. Although these results are not expected, other studies investigating emotions in CPS also did not find a significant influence of emotions on performance [16,73]. This is surprising as previous research has shown how negative affect affected problem-solving performance [74].

One explanation for our findings could be that the induced emotions were not "strong" enough or that the induction was unrelated to the simulation and, thus, learners might fail to connect emotionally across these disparate stimuli. A manipulation check showed that participants experienced the emotions intended to be triggered by the short video clips for happiness and anger, but less so for fear and trust. Many in the trust group expressed feeling happiness in the manipulation check. Yet, comparing performance across self-reported emotions did not show significant CPS performance differences.

A second explanation could be that some participants did not have any emotional investment in the simulation at all, were not interested in it, or did not see their performance as important. Our observations and the informal comments after the experiment, however, show that participants took ChocoFine very seriously and enjoyed working on ChocoFine. Nevertheless, future research should explicitly assess this motivational component as well.

A third explanation for the non-significant findings could be that not one emotion, per se, is ideal for the whole CPS process. Successful CPS demands at different times defining goals, gathering information, developing plans, evaluating decision alternatives,

implementing decisions, and monitoring the outcomes and the whole process [75]. For defining goals, it might be, for example, ideal to be calm and relaxed. When coming up with solution alternatives, a wide resolution level might be conducive, such as in a happy state. For implementing decisions in a frustrating situation, one could be courageous and potentially be a little aggressive without having too many self-doubts. Thus, at different times of the CPS process, different emotions would allow thinking differently and would be more conducive to performance than other emotions. Future research could investigate emotions specifically related to these CPS steps. The key, then, would be a variability of emotions and emotion regulation. Other research on mathematical problem solving has shown the change of emotions over time while working on a math problem [76,77] or working on logic problems from the law school admissions test [78]. Additionally, research on children and adolescents' executive control suggests that coping, emotion regulation, and decision making interact and have to be studied together [79], especially the two forms of metacognitive executive function (dorsolateral prefrontal cortex), including self-awareness and the emotional/motivational executive function (orbitofrontal and medial frontal lobe), which is related to the ability to coordinate cognition, emotion, and motivation, could be studied further in CPS [80].

The non-significant findings regarding the four emotions could also be related to simulation characteristics. ChocoFine performance data, i.e., total capital, steadily decreases for almost all participants. Every month, participants see the amount of capital left and the consequences of their decisions from the previous months. Most likely, seeing the decline in capital is frustrating, and although participants start initially with the induced emotion, the emotion could have changed into negative affect over time. Failing to solve a problem and seeing the declining account balance will result in cognitive disequilibrium and confusion [81]. If this equilibrium cannot be restored through ones' problem-solving skills, participants will feel frustration and negative affect. Other research on task difficulty has shown that with increase in task difficulty, negative emotions increase [6,82].

The second hypothesis of this study was related to emotion regulation. As research on emotion regulation has shown [60,61], it might not be initial emotional experience but emotion regulation that is related to CPS performance [83,84]. Emotion regulation was assessed with six subscales of emotion regulation styles: Positive Reframing, Self-Reflection, Boost of Self-Confidence, Flight Tendency, Resignation, and Aggression. The Cronbach's alpha reliabilities and fit indices of Confirmatory Factor Analyses were acceptable for the scales with only five items each. Results showed some significant relationships between emotion-regulation strategies and CPS performance. At the beginning of the simulation, in months 2 and 3, positive reframing was negatively related to performance. Telling oneself, for example, "It is not so bad" was not an effective strategy to perform well. As mentioned previously, since these are correlational data, positive reframing could be a consequence of low performance, or it could be a cause of low performance.

Regression analyses revealed that 17% in CPS performance could be explained by the six emotion-regulation strategies. A significant predictor was high aggression, which was positively related to performance. This is surprising at first sight. Aggression, however, is an approach emotion. High activation and high selection threshold as two components of aggression provide the necessary energy to persevere and could trigger helpful CPS strategies, such as searching for information or dealing with competitors and sticking with a specific problem. Similarly, another study found that frustrating participants by putting them in a "nasty" environment (where participants can hardly perform well and only receive negative feedback) compared to a "positive" environment (where participants easily perform well and only receive positive feedback) leads to more search for information and better performance [73]. Thus, aggression or frustration could also motivate one to succeed.

This study had several limitations. Due to the removal of outliers, the sample size of 83 is relatively small. Second, the induced emotions might not have had a long-lasting effect to influence performance in a simulation that lasted 1.5 h. The emotion intensity might have declined over time. Third, some studies have found working memory to be a predictor of

CPS performance even after controlling for intelligence [85]; other studies have not found an effect of intelligence, but instead an effect of working memory [86]; and other studies have not found an effect of WM capacity on CPS performance [87]. We did not control for intelligence nor working-memory capacity, which might have been related to CPS performance. Fourth, it might be controversial to include the emotion trust in our study. It is not one of the six basic emotions studied so frequently (anger, sadness, happiness, disgust, fear, and surprise). Yet, as mentioned previously, trust is an important emotion in the educational context and in social relationships, and some emotion researchers include trust as a basic emotion [57]; see also eight basic emotions: anger, anticipation, joy, trust, fear, surprise, sadness, and disgust [58].

Future research should have a closer look at how emotions are regulated over time during the CPS process and how emotions are related to cognitive CPS strategies [88,89]. One could simply interrupt participants at specific times and ask them about the emotion they are currently experiencing. Participants could then also rate the emotion intensity and respond to open-ended questions regarding emotion regulation. This way, emotion regulation could be connected better to the specific task situation and CPS strategy. Different emotions need to be regulated differently to be conducive to problem solving, especially anger, which usually has a maladaptive effect on CPS. Thus, an investigation of how anger can be transformed over time would be an interesting topic for future research, considering that in the current study, aggression was positively related to performance.

Future research should also investigate the role of culture during emotion regulation and problem solving. The current study has been conducted with a student sample in the United States. As cultural background can influence how people experience emotions and to what extent they can express certain emotions and regulate them [90,91], future research should be conducted in other cultures as well.

Regarding applications, there are numerous advantages of microworld technology in the educational context. Following constructivism, they allow self-motivated and self-directed interactive learning experiences [92,93]. Dealing with uncertainty and complexity is often stressful and a key requirement of many professional environments. Thus, microworlds provide learning opportunities to engage with these requirements, to apply knowledge, and to improve one's CPS [94,95].

5. Practical Implications

Working on microworlds is often experienced as being stressful, such as working on complex tasks in real life; for example, developing a new product in a company or trying to solve conflicts with children or partners. Microworlds and real-life tasks not only challenge the participants' problem-solving and decision-making skills but also trigger emotions and require our motivation to persist. These emotions can provide helpful directions for CPS. Having positive emotions can help widen our decision options. Having negative emotions, for example, when being overwhelmed or not successful, can help us be more self-critical and reflect about possible decision alternatives. Important, however, is also our ability to regulate our emotions and not be stuck in them. Emotion regulation means transforming our emotions and thoughts according to the changing demands of the situation. Under this perspective, emotions provide an immediate assessment of the situation. Transforming these emotions is then key to successful problem solving. Thus, the first step is to become aware of one's emotional and related physiological reaction in such a situation, then to understand what this reaction tells the problem solver, and then to use the emotion to inform how to "aggressively" approach a given problem, selecting an area of emphasis and focus, provided one does not become paralyzed and overwhelmed. Emotion regulation also helps to critically self-reflect about the decisions made and the consequences of these decisions. Motivation, emotion, and cognition all work together like an orchestra when solving complex, uncertain, and dynamic problems.

6. Conclusions

To conclude, this study investigated the role of emotions during CPS, specifically if certain emotions can lead to better performance and if emotion regulation is related to better performance in the ChocoFine simulation. Results showed no significant differences between the four emotion groups: trust, happiness, fear, and anger. Results from correlation analyses showed, however, a negative relationship of positive reframing and performance at the beginning of the simulation. Regression analyses showed that the six emotion-regulation strategies significantly predicted CPS performance. High aggression significantly predicted CPS performance at the end of the simulation. While emotions and CPS have been rarely investigated, results suggest that the in-depth study of emotion regulation during the CPS process would be an interesting avenue for future research.

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