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Examining the regulation of motivational and comprehension-related problems during collaborative learning

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Abstract
To be able to collaborate effectively and efficiently has been described as a complex and crucial twenty-first century skill. During collaboration, however, a variety of problems may emerge that require groups to engage in effective regulation processes, which is a complex task in itself. Up to now, little is known about (a) what types of strategies learners of such groups typically apply to regulate their learning, and (b) on which social levels (self vs. co vs. shared-level) they apply these strategies to account for different kinds of problems that may surface during collaboration. To address these questions, we developed four case vignettes that described a study group during exam preparation, in which problems were systematically varied in a 2×2 within-subjects design (present vs. absent motivational or comprehension-related problems). Using an open-ended format, $N=278$ students were asked to describe (a) the strategies they would apply, and (b) the social levels at which they would apply these strategies in each of the four problem situations. Answers were coded and quantified by aid of an in-depth, theory-based coding scheme. Results showed that students react to motivational problems with more motivational but less cognitive strategies and to comprehension-related problems with more cognitive, but a similarly high use of motivational strategies. Thus, students seem to tackle motivational problems in a more problem-sensitive way than comprehension-related problems – a finding which was found also across social levels. These findings bear important implications for process-related research on social regulation and for the design of interventions.

Keywords Co-regulation · Collaborative learning · Comprehension-related problems · Motivational problems

Aims of the study

Compared to individual learning, having learners collaborate on a certain topic can be associated with numerous advantages: Through collaboration, learners may engage in high-level socio-discursive learning activities (Schwaighofer et al., 2017), reach more positive

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motivational states (Järvenoja & Järvelä, 2009), and develop more favourable attitudes towards the learning material (Springer et al., 1999). All this may foster the acquisition of in-depth knowledge and competencies (Kyndt et al., 2013). It is thus not surprising that the ability to collaborate effectively and efficiently has been described as a crucial twenty-first century skill (e.g., Clark et al., 2010; Hadwin et al., 2018; Splichal et al., 2018).

Yet, to collaborate effectively in learning settings is a very complex skill that requires learners to share their knowledge, and to coordinate their actions towards a joint learning goal (Kaendler et al., 2015). In line with this, empirical research shows that not all groups are capable of exploiting the potential of collaborative learning to achieve positive outcomes (e.g., Weinberger et al., 2010). In particular, this seems to be the case in study groups that are characterized by a low degree of external scaffolding (Kollar et al., 2018). For example, when students come together to study for an upcoming exam, many groups run the danger of not effectively regulating their learning process. In fact, successfully regulating collaborative learning can be seen as a complex skill in itself that requires students to select suitable regulation strategies and, as an underlying precondition, have and apply strategy knowledge (Melzner et al., 2020) that leads them to arrive at metacognitive decisions regarding what strategies to select and apply when being faced with specific regulation problems. Yet, we expect that groups may differ in their ability to select and apply the right strategies for the right kinds of problems, i.e., groups may be more or less *sensitive* to the actual regulation problems they experience.

Let us assume a group that has limited understanding of important technical terms related to the current topic: In the context of this article, being sensitive to this problem would mean that the group uses strategies that approach the problem directly (e.g., discussing technical terms to arrive at a joint understanding). In contrast, the group would be less problem-sensitive when they use self-rewards for studying for a predefined amount of time, since this strategy tackles the problem only indirectly. Recent research on group regulation further extends the problem of limited conditional strategy knowledge to a social level as well: There, the question is whether group members know which problems to best tackle as a group, and which problems rather to solve individually (e.g., Järvelä & Hadwin, 2013): While the problem of having difficulties understanding a scientific concept might best be regulated by looking up descriptions (as an individual), the problem of being unmotivated to study might better be regulated as a group (e.g., by jointly thinking about how to make subject matter information personally relevant). Knowing more about the extent to which (university) students have or lack conditional strategic knowledge on how to deal with different kinds of problems during collaborative learning in a sensitive way is important because it may inform the design of scaffolds for collaborative learning.

Therefore, in this article, we investigate how study group members regulate their learning when they are confronted with different kinds of (experimentally induced) regulation problems, both with respect to the types of strategies they use and the extent to which they apply these strategies at different social levels within the group.

Motivational and comprehension-related problems during collaborative learning

At university, students often deliberately form study groups to prepare for upcoming exams (Koivuniemi et al., 2017). Learning in such groups is characterized by a low degree of external regulation: not an external instance such as a teacher or tutor, but instead the groups themselves make important decisions on when, how, and what to study together (Hron & Friedrich, 2003; Weinert,

1982). Yet, as empirical research shows, groups are often overstrained by the need to regulate their learning effectively. In a study by Weinberger and colleagues (2010), for example, Educational Science students were asked to solve authentic educational problems by aid of a scientific theory, either as individuals or in triads. Results showed that students who solved cases in triads acquired less domain-specific knowledge through problem-solving than students who worked individually. Obviously, triads were not successful in regulating their learning successfully. This interpretation was corroborated by the results of a third condition, in which triads' collaboration was externally regulated through the provision of a collaboration script. Students from this condition outperformed students from the two other conditions with respect to knowledge acquisition. Similar results were obtained by Escudero et al. (2013), Järvenoja et al. (2013) and Rybczynski and Schussler (2011).

While problems that may occur during collaborative learning may be manifold, this article focuses on two kinds of problems that have been reported as surfacing quite frequently during collaboration (see Malmberg et al., 2015): (a) *motivational problems*, which we define as problems that make it difficult for learners to initiate, guide and maintain goal-directed studying behaviors (Schunk et al., 2008), and (b) *comprehension-related problems,* which we define as problems of learners to grasp and understand subject matter information (Dewitz & Dewitz, 2003). Examples for motivational problems are that groups may display low interest in the topic they are dealing with, see little value in the usefulness of studying the topic, or have low expectancy to succeed in a subsequent exam they are studying for (Engelschalk et al., 2016; Järvelä et al., 2010, 2013; Järvenoja & Järvelä, 2009). Exemplary comprehension-related problems may refer to difficulties in understanding the learning material, in making connections between different aspects of the content to be learnt, or in transferring that content to new problems (Koivuniemi et al., 2017; Malmberg et al., 2015; Näykki et al., 2014).

So far, little is known about how groups cope with motivational and comprehension-related problems during collaborative learning. In one of the few studies that are available on this issue, using a qualitative case study approach, Järvelä et al. (2013) describe a small group with comprehension-related problems (difficulty in identifying important content to discuss) that reacted with efforts to mutually motivate each other, and to split the learning material up and distribute it among group members (a metacognitive strategy). Another group, which experienced motivational problems (i.e., that the topic would not be very practice-oriented and, thus, boring) also applied strategies to motivate each other. Thus, interestingly, while the second group applied a strategy that directly matched the problem (a motivational strategy to regulate a motivational problem), this was not the case for the first group.

This finding provides tentative evidence that groups may be more sensitive towards motivational problems (as the second group directly applied motivational regulation strategies when a motivational problem appeared) than towards comprehension-related problems. Yet, it is an open question to what extent these observations are generalizable. In particular, empirical studies seem to be missing that (a) systematically vary the kinds of problems that may occur during collaboration, and (b) do so using larger samples.

What types of strategies are promising to deal with motivational and comprehension-related problems?

If the question is how sensitively groups react to the kinds of regulation problems they experience during collaboration, it is important to portray the range of regulation strategies that are described in the literature. This can be done by referring to prominent learning

strategy typologies that have particularly been developed in research on self-regulated learning (e.g., Boekaerts, 1999; Friedrich & Mandl, 2006; Zimmerman, 2008). Even though there are slight variations among these models, both with respect to the labelling of subgroups of strategies and with respect to how to classify specific strategies, at least the following types of strategies can be distinguished: (1) *Cognitive strategies,* that are directed at processing information to be learnt, including both in-depth (e.g., practically applying learning content to new problems) and surface-oriented strategies (e.g., reciting learned facts) that are directed at the acquisition of knowledge. (2) *Metacognitive strategies*, that refer to planning, monitoring, and evaluating the learning process (e.g., comparing the actual and target state). (3) *Motivational regulation strategies,* that aim at initiating, guiding, and maintaining goal-directed studying behaviors (e.g., identifying personal relevance of learning content; see Wolters, 2003). And finally, (4*) resource-oriented, non-motivational strategies* that control environmental factors and attention (e.g., asking learning partners for clarifications, looking for internet resources to better understand concepts; see Melzner et al., 2020, for a more elaborated distinction).

We assume that problems that may arise in study groups can be regulated more or less problem-sensitively. In a very straightforward way, we regard a strategy as problem-sensitive when it "matches" the nature of the problem to be regulated (Malmberg et al., 2015). According to this view, a sensitive regulation of a motivational problem would be to use mainly motivational strategies, while a use of cognitive strategies would be sensitive for the regulation of a comprehension-related problem. This "category-based" view of problem-sensitivity seems to be rather broadly advocated in the literature. For example, Hulleman and Harackiewicz (2009) showed that prompting students to write about the personal significance of the learning material at hand (i.e., engage in a motivational regulation strategy) led to an increase of interest in the course, especially for students with a low expectancy to succeed in the course (a motivational problem). Furthermore, Malmberg et al. (2015) provide evidence that for regulating comprehension-related and motivational problems, the application of cognitive and motivational strategies is more problem-sensitive than the application of resource-oriented non-motivational strategies. In their study, 30 groups collaborated alternately in virtual and face-to-face learning environments over a period of two months. Qualitative analyses revealed that in less successful groups, comprehension-related and motivational problems were regulated in particular with resource-oriented, non-motivational strategies, while higher-performing groups limited themselves in particular to the application of cognitive and motivational strategies.

Even though the aforementioned studies provide evidence for the view that motivational regulation strategies work best for the regulation of motivational problems, and that cognitive strategies work best for comprehension-related problems, an open question however is whether students are actually aware of this and orient their choice of regulation strategies on the categorization of the particular problem at hand (i.e., whether they possess conditional strategy knowledge that guides them in the selection of the "right" strategies; Steuer et al., 2019). That this might indeed be the case has been shown at least with respect to motivational problems in individual learning settings: Engelschalk et al. (2015) asked fifty-four teacher students to rate their successfulness in motivating themselves when being confronted with six typical motivational problems, and to report in half-structured interviews what kinds of strategies they would use in each of these situations. Results showed that when students had low success expectations, they reported less strategies to increase situational interest, but more frequently strategies for goal-oriented self-instruction and environmental control than value propositions. The authors concluded that learners are at least somewhat "sensitive" to different types of motivational problems, as they seem to

react selectively with different regulation strategies to different kinds of problems (see also Engelschalk et al., 2017; Steuer et al., 2019).

Even though the results by Engelschalk and colleagues (2015) only refer to motivational regulation problems in individual (i.e., non-collaborative) learning settings, we use them as first evidence to assume that also in collaborative learning situations, students will regard strategies that do not directly match the types of problems they experience as less effective, and therefore apply them to a lower extent as compared to strategies that match the problem in the way just described.

At what social levels do collaborators regulate motivational and comprehension-related problems?

Investigating the sensitivity by which students react to different kinds of regulation problems *within groups* (as opposed to individual learning settings) opens up another relevant question, namely whether the presence of different kinds of regulation problems also has an impact on the groups' decision to cope with the problem at the group level at all, or whether they leave certain problems to individual group members to regulate. Järvelä and Hadwin (2013) proposed that study groups may regulate their learning process at three different social levels. Learners may first use regulation strategies at the *self*-level. This means that they apply these strategies without making them visible for the other group members, in order to sustain, to change, or to direct *their own* cognitive, metacognitive, affective, or behavioral processes (DiDonato, 2013). Second, at the *co*-level, a student may try to support single fellow group members to improve *their* learning processes. Third, groups may also share, negotiate, and synthetize strategies to attain joint learning goals at the whole-group level (Miller & Hadwin, 2015), which Järvelä and Hadwin (2013) termed as an instance of *shared* regulation.

To illustrate how the same strategy can be used on each of these three levels, imagine a group in which learners have the problem of an unclear understanding of important topic-specific concepts (such as "light-dependent reaction" and "light-independent reaction" within the topic "photosynthesis"). At the self-level, one member of the group may mentally self-explain these terms to herself, in order to arrive at an improved understanding. At the co-level, one member of the group may ask one other member of the group to explain these concepts to her. And at the shared-level, the whole group may jointly develop a shared understanding of these concepts through mutual discussion.

So far, research on collaborative learning seems to assume that regulating processes at the shared-level is effective with respect to a broad range of problems. For example, in a study by Järvelä, et al. (2013), students from a Master's program on Learning and Educational Technology were asked to work on a series of tasks that asked them to apply concepts from research on self-regulated learning to authentic problems in groups of three. Strong groups turned out as tackling very different kinds of problems at the shared-level. For example, in one group, one member was missing for one of the group meetings. The remaining students then jointly developed a plan on how to distribute work among the two of them to compensate for the missing third member. Another group that reported technical problems with the learning platform to be used described that they switched to other communication modes to keep their collaboration up. One group that turned out to be weak, in turn, resorted to splitting up the task among the individual group members, thereby making regulation a self-level activity.

As this research shows, learners may attribute the group greater power to deal effectively with some problems than with other kinds of problems. Theoretically, it might be that learners regard groups as especially powerful when it comes to the regulation of motivational problems (because group members may motivate each other, for example by "reminding each other that we all have a life beyond [studying]"; see Järvelä et al., 2013), and thus decide to deal with such problems as a group as a whole. Comprehension-related problems, in contrast, might be seen as rather "private" problems that every single group member needs to deal with on their own (and not make them a particular topic of group discourse). One barrier to discussing one's own comprehension-related problems at the group level might for example be to avoid being regarded as incompetent (Darnon et al., 2007).

So far, empirical research that is based on the three-level-model proposed by Järvelä and Hadwin (2013) is characterized by a strong qualitative focus. For example, Malmberg and colleagues (2017) investigated what regulation strategies at the three social levels could be observed in groups that collaborated in a two-month mathematics course. Results from qualitative analyses and lag sequence analysis showed that the most frequent strategies students used were co-regulated planning (e.g., prompting another group member to proceed to solve a task), and monitoring (e.g., suggest sequences to accomplish tasks). Most interactions at the shared-level referred to planning (e.g., joint adjustment of the task assignment) with a focus on task execution.

In another study, Vauras and colleagues (2003) examined how self- and co-regulated learning took place when groups played a math-related instructional game twice a week over the course of two months. A qualitative case study of one selected high ability study group showed that the social level of regulation fluctuated during collaborative work. However, the authors assume that students do not regularly show this fluctuation, and that shared regulation might appear more frequently in more difficult tasks.

Even though research on group regulation processes has flourished over the past years, empirical studies that look specifically into the social levels at which groups deal with motivational and comprehension-related problems are scarce. It is thus an open question whether (learners in) groups prefer to apply regulation strategies at certain social levels over the application of regulation strategies at other social levels depending on the kind of problem they experience. Finding answers to this question might inform further research that looks into whether regulating different kinds of problems at different social levels actually is differentially effective, and consequently develop scaffolds that might help groups decide what problem to tackle at what social level.

Research questions and hypotheses

This study investigates the extent to which groups have strategic conditional knowledge regarding when to select what kinds of regulation strategies at what social levels during collaborative learning. Using a vignette-based approach, we look at the effects of the presence or absence of motivational and comprehension-related problems during small group learning on students' use of different regulation strategies at the self-, co- and shared-level. In other words, participants were asked to imagine being part of a voluntary study group that encounters motivational and/or comprehension-related problems during collaboration, and were demanded to name and describe the strategies they would use in these different situations, using

an open-answer format. More specifically, our research questions and hypotheses were:

RQ1: What are the effects of the presence versus absence of motivational problems, comprehension-related problems and their combination on the extent to which students apply cognitive and motivational regulation strategies?

H1: We assume students to respond sensitively to different kinds of problems. Thus, when confronted with motivational problems, we expect students to actively select more motivational regulation strategies than in situations without motivational problems. In addition, we expect that when there are motivational problems, students select fewer cognitive strategies than when these problems are not present (H1a). When confronted with comprehension-related problems, we expect students to respond with more cognitive strategies than in situations without such problems. In addition, we assume that in light of comprehension-related problems, students select fewer motivational strategies than in the absence of such problems (H1b).
H2: When faced with both motivational and comprehension-related problems, we expect students to select the highest combined frequencies of regulation strategies (cognitive and motivational). In this situation, two problems are present that require specific regulation. Therefore, the use of cognitive strategies should be higher than in the condition without problems, and in the condition in which only motivational problems are present. Likewise, the use of motivational strategies should be more frequent than in the condition without problems and the condition with only comprehension-related problems. In the absence of problems, we expect students to display the smallest combined frequencies of regulation strategies. In this situation, the result of students' problem analyses should be that no activation of problem-specific strategies is necessary as there are no problems to be regulated.

In addition, we look at learners' sensitivity to different kinds of regulation problems from a perspective of the social levels at which learners in groups apply different regulation strategies. As previous research on this issue is scarce and ambiguous, we however did not formulate hypotheses regarding this research question. Instead, we ran an exploratory analysis to see whether there would be differences in the use of regulation strategies at the self-, the co- and the shared-level depending on the kinds of problems that students were confronted with. Thus, RQ2 was:

RQ2: What are the effects of the presence versus absence of motivational problems, comprehension-related problems and their combination on the extent to which students apply regulation strategies at different social levels (self vs. co vs. shared) of regulation?

Method

Sample and design

Subjects were $N = 278$ university students from an introductory lecture in Educational Science at a German university. Participation was voluntary, and the data was collected

completely anonymously. Participants were between 18 and 37 years old (M_{Age} = 21.48, SD_{Age} = 2.59). They were on average in their 3rd semester of studies (M_{Sem} = 3.40, SD_{Sem} = 1.70). Participants were asked to imagine they were part of a voluntary study group studying for an exam, and to read a series of four case vignettes that reported that their study group had either motivational problems or comprehension-related problems, or both, or none of those problems, thereby establishing a 2 × 2-factorial within-subjects design.

Case vignettes

All materials were presented on paper. Each participant received a booklet including four case vignettes (i.e., one case vignette for each of the four situations in a randomized order). Each case vignette described a study group that prepared for an exam. Participants were asked to imagine being a member of that group. In the conditions that presented motivational problems, the study group was described to exhibit low motivation concerning the subject matter (vs."high motivation" = no motivational problems). When vignettes presented comprehension-related problems, they stated that the group had "low knowledge" (vs. "high knowledge" = no comprehension-related problems). When neither motivational nor comprehension-related problems were presented, the vignette said that the group had 'high knowledge' and "high learning motivation". In the combined condition, the vignette described the group as having "low knowledge and low learning motivation" (for the complete vignettes, see Table 1).

After each vignette, participants were asked to indicate if they would "do something to ensure a high quality of learning" at (a) the self-level ("Would you personally do something in this situation to ensure a high quality of your own learning?"), at (b) the co-level ("…to ensure a high quality of other individual group members' learning?"), and (c) at the shared-level ("…to ensure a high quality of your group's learning?"). In case they indicated that they would do something, they were asked to write down what exactly they would do in this situation at the particular social level of regulation. For this purpose, three blank text fields, i.e., one blank text field per social level of regulation, were listed below each vignette. To familiarize students with the distinction of the three social levels, an example vignette that introduced a soccer playing scenario (soccer team has high vs. low skills or motivation with respect to a training session) was presented on the first page of the booklet, and in which strategies were suggested to control the soccer situation (e.g., as a skills-related strategy at the self-level:"I practice my shooting technique"; as a motivation-related strategy at the shared-level:"We eat pizza together to strengthen our team spirit").

Variables

Types of strategies The unit of analysis was each strategy that students mentioned in any of the text fields. In cases in which they mentioned more than one strategy in one text field, the answer was segmented accordingly. To analyse the data, we developed a coding scheme that was based on the strategy typology introduced above that merged strategy typologies from the literature (e.g., Boekaerts, 1997; Friedrich & Mandl, 2006; Zimmerman, 2008; see Table 2). A strategy was classified as *deep processing strategy* when it was directed at gaining a better understanding of the learning material. Examples were "I link new content information to my prior knowledge" or "I try to explain the content to my co-learners".

Table 1 The four vignettes representing the four problem situations (= quasi-experimental conditions)

Main part of the vignette (1)	You are in a study group with three fellow students. They meet regularly and are a well-rehearsed team. Currently you are preparing for an exam together with your group that will take place in three weeks. With respect to the material to be learnt for the exam, all group members have …	
Additional part (2)		
	No Comprehension-related Problems	Comprehension-related Problems
No Motivational Problems	…high knowledge and high learning motivation (="without regulation problems")	…low knowledge and high learning motivation (="only comprehension-related problems")
Motivational Problems	…high knowledge and low learning motivation (="only motivational problems")	…low knowledge and low learning motivation (="motivational and comprehension-related problems")

Table 2 Coding scheme for the type of mentioned regulation strategies, along with examples

Strategy types	Observed example
Deep processing strategies (elaboration)	"I link the content with different pieces of prior knowledge." "I try to explain it to the others." 'I look at the learning material myself."
Surface-oriented strategies	"I memorize the learning content." "I write index cards." "We repeat the content together."
Metacognitive strategies	"I prepare tests to probe my knowledge." "We make plans on how to continue our joint learning." "We ask each other about what knowledge we acquired."
Motivational regulation strategies	"We motivate each other." "I use my own motivation." "I try to keep up studying."
Resource oriented, non-motivational strategies	"I make sure that I learn in a non-distracting environment." "I search for additional literature." "I choose study places where I can concentrate well."
Other strategies	"We discuss different questions." "We help each other." "We immediately clarify questions."
No strategies	"Motivation is available." "I am already capable of highly competent thought processes." "I definitely do not have a vague idea anymore."

Surface-oriented strategies were coded when answers described strategies that serve to better memorize learning content. Examples were "I use index cards to better remember the content" or "I repeatedly go through the learning material to memorize it the best I can". A strategy was considered *metacognitive* when it referred to activities of planning, monitoring, or controlling the learning process. One example was "We jointly prepare a learning plan"; another was "I repeatedly probe my own knowledge during learning". The code for *motivational regulation strategies* was assigned to answers that referred to activities that aimed at maintaining or increasing learning motivation. Examples were "We try to find things that motivate us, such as rewards" or "I also study at home so that I don't do worse on the exam than my peers". A strategy was coded as *resource-related, non-motivational* when it served effort or time management, or attention control. Examples were "We look for a quiet space to study" or "I urge the group to only focus on the most important topics". Finally, a strategy was classified as *other strategy* when it contained statements that could not clearly be assigned to one of the aforementioned categories. Examples were "Working together on it" or "Providing information".

Ten percent of the data were coded by two independent coders who had been trained in the application of the coding scheme. Interrater reliability turned out to be sufficient (Cohen's Kappa = 0.77). Because of the focus of this study on cognitive and motivational regulation strategies, we collapsed the codes "deep processing strategies" and "surface-level strategies" into one code "cognitive strategies", as we had no hypothesis on whether and how the presence or absence of a particular regulation problem would differentially affect the selection of these two kinds of strategies. Also, we excluded all strategies that neither were cognitive nor motivational. Together, the answers that were included in the subsequent analyses accounted for 61.29% of all reported strategies. For the analyses regarding RQ1, we looked at the frequencies of cognitive and motivational regulation strategies separately.

Social levels With respect to RQ2, we counted the total frequencies of cognitive and motivational regulation strategies that participants mentioned for each of the three social levels (i.e., we computed frequency scores for all types of strategies for each text field representing a social level separately). Unfortunately, not all isolated answers provided clear hints towards the social level they were directed at. For example, one exemplary student answer was "find a quiet spot for studying", which left it open at which social level this strategy would be located. Therefore, it was not possible to only show the coders the different answers independent from the information at which level participants located them. In cases in which explicit indicators towards the social level were present (e.g., "I try to explain things to others", as an exemplary statement at the co-level), we however found no indication that participants had particular difficulties differentiating between the social levels. Exemplary answers for strategies at the self-level were "I try to relate the learning material to my prior knowledge", and "I try to stay on the ball during learning". For the co-level, students wrote for example "I try to explain things to my learning partners", and "I let the others share their prior knowledge". Examples for strategies at the shared-level were "We recapitulate the learning material together", or "We create a mind-map together".

Data analysis

To answer RQ1 and RQ2, we conducted a $2\times2\times3\times2$-factorial ANOVA that included "motivational problems" (present vs. absent), "comprehension-related problems" (present vs. absent), "social level of regulation" (self-level vs. co-level vs. shared-level), and "strategy type" (motivational regulation strategies vs. cognitive regulation strategies) as repeated measurement factors. The dependent variable was the frequency by which regulation strategies were reported. For all analyses, the alpha level was set to 5%. Since a Mauchly's test indicated a violation of the sphericity assumption for the *levels of regulation* ($\chi^2(2)=7.9$, $p<0.001$), with ε as the extent of the violation >0.75, a Huynh–Feldt correction of degrees of freedom was applied ($\varepsilon=0.98$). Furthermore, a Shapiro–Wilk test of the residuals of the 24 factor level combinations to be tested suggested deviations from the normal distribution, $W(278)\leq0.82$, $p<0.001$. However, since such a violation (1) at cell frequencies >25 (given in this study) usually is without significant consequences, (2) ANOVA with repeated measurements is relatively robust against violations of its assumptions, and (3) the effect of the violation of normality is valued low in balanced designs, no transformation of the data was carried out (e.g., Cleff, 2019).

Results

Effects of motivational and comprehension-related problems on cognitive and motivational regulation strategies (Research Question RQ1)

Table 3 shows the descriptives for the number of cognitive and motivational strategies in the four experimental conditions across the three social levels.

Research Question RQ1 asked for the effects of the presence of the two different kinds of regulation problems on the frequencies of cognitive and motivational regulation strategies. To illustrate the results, Fig. 1 summarizes the number of strategies across the four experimental conditions (thereby collapsing strategies from the three social levels). Here, descriptive statistics

showed that cognitive strategies were reported most frequently in the absence of motivational problems (i.e., in the conditions "without regulation problems" and "only comprehension-related problems"). In the condition "with motivational and comprehension-related problems", cognitive strategies were mentioned less frequently, but still slightly more often than in the condition "only motivational problems". Furthermore, when there were no problems or only comprehension-related problems, students reacted with only few motivational strategies. More motivational strategies were reported when only comprehension-related problems or both kinds of problems were present.

Initially, a $2 \times 2 \times 3 \times 2$-factorial ANOVA (for a summary of all effects, see Table 4) with repeated measures showed a significant main effect of the factor *comprehension-related problems*, and the factor *motivational problems*. While the main effect for comprehension-related problems indicates that students respond with more strategies when these problems are present compared to when they are not, the main effect of *motivational problems* indicated that students seem to report more strategies when motivational problems are not present rather than when they are present. In addition, there was a significant main effect of the factor *strategy type*, which indicates that overall, cognitive strategies are mentioned more often than motivational strategies. Yet, this effect seems to be due to instances where no motivational problems are present.

Hypothesis 1a assumed that when motivational problems are present, students would react with more motivational, but less cognitive strategies than if there were no motivational problems. To test this hypothesis, we checked the interaction effect between *motivational problems* and *strategy type*, which was significant. Bonferroni-corrected post-hoc comparisons showed that students respond to motivational problems with less cognitive ($p < 0.001$), but more motivational strategies ($p < 0.001$), as compared to situations without motivational problems. Thus, Hypothesis H1a was confirmed.

Hypothesis 1b assumed that in the presence of comprehension-related problems, students would react with more cognitive strategies and with less motivational strategies as if there were no such problems. This hypothesis was tested by considering the interaction effect of the factors *comprehension-related problems* and *strategy type,* which was significant. As expected, Bonferroni-corrected post-hoc comparisons showed that students list more cognitive strategies when comprehension-related problems are present compared to when they are not ($p < 0.001$). However, there was no difference in the frequency of motivational strategies in situations with comprehension-related problems, and in situations without these problems ($p = 0.686$). As a result, Hypothesis H1b was only partially confirmed.

Finally, Hypothesis 2 assumed that students would react with most problem-sensitive (i.e., cognitive plus motivational) strategies when motivational and comprehension-related problems are present at the same time. As a consequence, we examined the three-way-interaction of the factors *motivational problems*, *comprehension-related problems* and *strategy type*. Contrary to our assumption, this interaction effect was not significant. Accordingly, Hypothesis H2 was not confirmed.

Effects of motivational and comprehension-related problems on strategies at the self-, co-, and shared-level (Research Question RQ2)

Research Question RQ2 asked for the effects of the presence vs. absence of motivational and comprehension-related problems on the frequencies of strategies at the different social levels of regulation introduced by Järvelä and Hadwin (2013). Due to the scarcity of prior research on this topic, we formulated no hypotheses and instead conducted an exploratory

Table 3 Means (standard deviations in parentheses) for numbers of motivational and cognitive regulation strategies in the four experimental conditions across the three social levels

	without regulation problems		only motivational problems		only comprehension-related problems		motivational and comprehension-related problems	
	Motivational regulation strategies	Cognitive regulation strategies	Motivational regulation strategies	Cognitive regulation strategies	Motivational regulation strategies	Cognitive regulation strategies	Motivational regulation strategies	Cognitive regulation strategies
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
No. strategies at self-level	0.58 (0.74)	0.47 (0.75)	0.57 (0.82)	0.36 (0.67)	0.12 (0.36)	0.83 (0.89)	0.20 (0.51)	0.77 (0.87)
No. strategies at co-level	0.27 (0.54)	0.30 (0.58)	0.28 (0.56)	0.22 (0.48)	0.15 (0.42)	0.56 (0.71)	0.09 (0.32)	0.47 (0.66)
No. strategies at shared-level	0.56 (0.80)	0.42 (0.72)	0.51 (0.69)	0.37 (0.63)	0.23 (0.49)	0.85 (0.79)	0.32 (0.62)	0.72 (0.79)

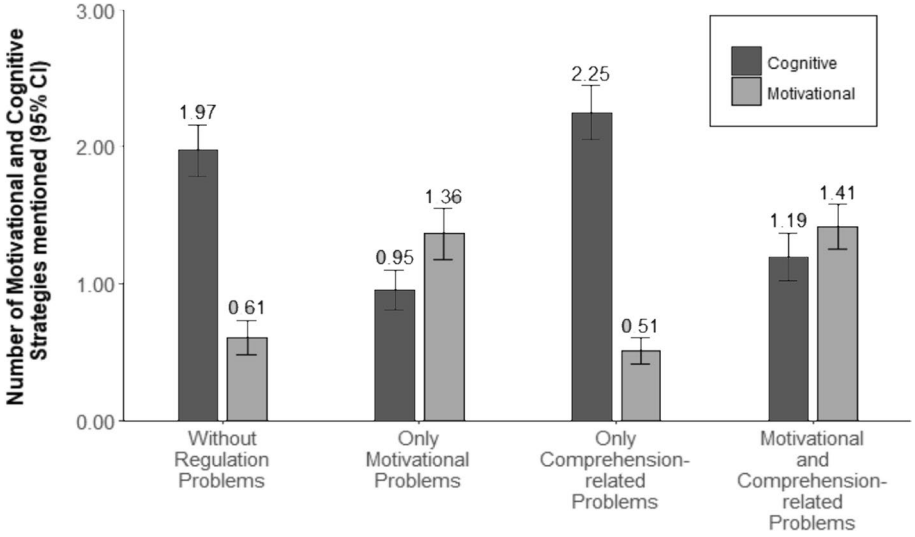

Fig. 1 Frequencies of motivational and cognitive strategies in the four experimental conditions

analysis. Since the sensitivity of regulation was no longer of interest for RQ2 (as we had no particular hypotheses on whether sensitivity would differ across levels), we ignored the differentiation between cognitive and motivational strategies for the purpose of these analyses and collapsed the two different strategy types into one variable.

Descriptive statistics (see Fig. 2) indicated that most strategies were located at the shared-level ($M = 1.50$, $SD = 0.32$), closely followed by the self-level ($M = 1.46$, $SD = 0.32$). The fewest strategies were reported at the co-level ($M = 1.18$, $SD = 0.89$). In addition, slightly fewer strategies across the three social levels of regulation were observed in the condition "only motivational problems" ($M = 1.16$, $SD = 0.30$) compared to the condition „without regulation problems " ($M = 1.30$, $SD = 1.29$), as well as for "only comprehension-related problems" ($M = 1.99$, $SD = 1.38$), and for the condition "with motivational and comprehension-related problems" ($M = 1.32$, $SD = 1.30$).

The aforementioned $2 \times 2 \times 3 \times 2$ ANOVA (see Table 4) showed a significant main effect for the factor *social level of regulation*. Post-hoc comparisons showed that students reported a comparable number of strategies at the self and shared-level ($p = 0.999$) and significantly fewer strategies at the co-level (each $p < 0.001$).

Further, we found a significant interaction between the factors *motivational problems* and *social level of regulation*. Post-hoc comparisons with Bonferroni correction revealed that when motivational problems are present, students react with fewer strategies at the co-level than when these problems are not present ($p = 0.018$). A similar pattern was observed for the use of strategies at the shared-level between situations with versus without motivational problems ($p = 0.010$). However, we found no significant difference in the number of reported strategies at the self-level ($p = 0.690$). Also, we neither observed a significant interaction between the factors *comprehension-related problems* and *levels of regulation*, nor between the factors *motivational problems*, *comprehension-related problems,* and *levels of regulation*.

Table 4 Summary of effects of the 2×2×3×2-factorial ANOVA

Effect	*df1*	*df2*	*MSE*	*F*	*p*	η^2
Comprehension-related problems	1	277	2.53	5.844	.016	0.021
Motivational problems	1	277	1.94	4.497	.035	0.016
Social level	1.958	542.420	29.15	67.404	< .001	0.196
Strategy type	1	277	70.94	51.114	< .001	0.156
Comprehension-related problems * motivational problems	1	277	0.15	0.508	.477	0.002
Comprehension-related problems * social levels	1.990	551.306	0.12	0.447	.639	0.002
Motivational problems * social levels	2	554	0.82	3.457	.032	0.012
Comprehension-related problems * motivational problems * social level	1.973	546.638	0.38	1.600	.203	0.006
Comprehension-related problems * strategy type	1	277	3.74	7.715	.006	0.027
Motivational problems * strategy type	1	277	161.48	247.691	< .001	0.472
Comprehension-related problems * motivational problems * strategy type	1	277	0.40	0.933	.335	0.003
Social level * strategy type	2	554	0.53	0.956	.385	0.003
Comprehension-related problems * social levels * strategy type	1.939	537.053	0.18	0.546	.574	0.002
Motivational problems * social levels * strategy type	1.981	548.757	5.68	16.925	< .001	0.058
Comprehension-related problems * motivational problems * social levels * strategy type	2	554	0.69	2.250	.106	0.008

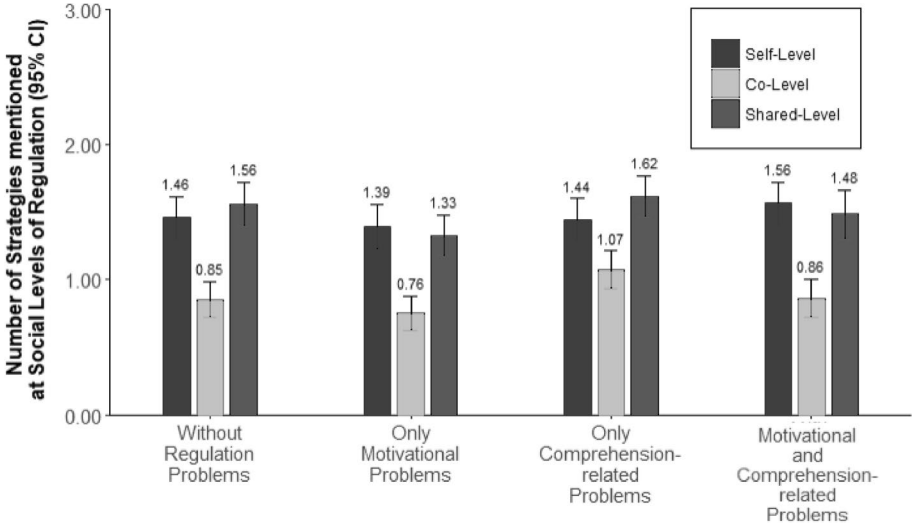

Fig. 2 Frequency of overall strategy use in the four experimental conditions

Discussion

The present study investigated the extent to which students in study groups are sensitive to (a) motivational problems, (b) comprehension-related problems, and (c) their combination, when it comes to the selection and application of cognitive and motivational regulation strategies, and to the social level of regulation at which they apply these strategies.

Regarding Research Question *RQ1*, and in line with our assumption that students would be sensitive to the kinds of problems that would pop up during collaboration, we expected that students would report more motivational, but less cognitive strategies in situations with motivational problems compared to situations in which motivational problems would not be present. We further assumed that students would apply more cognitive, but less motivational regulation strategies when they would face comprehension-related problems compared to when they would not, and that co-occurring motivational and comprehension-related problems would yield the highest frequencies of motivational and cognitive regulation strategies.

These hypotheses were largely, but not completely confirmed: In line with our expectations, students reported more motivational regulation strategies when they were confronted with a group situation in which motivational problems were present compared to when they were not. At the same time, cognitive strategies were very seldom reported when motivational problems were present (especially when the only kinds of problems were motivational). These results indicate that the way students react to motivational problems is both sensitive (Malmberg et al., 2015) and rather specific: when there is low motivation in the group, students seem to invest most of their efforts in (sensitive) strategies that directly aim at fixing those motivational problems, which in turn seems to go at the expense of an engagement in cognitive strategies. In a sense, students might regard putting effort into an increase of motivation as a necessary precondition for a subsequent engagement in cognitive strategies. In light of research indicating that different motivational prerequisites

such as interest (Jansen et al., 2016), achievement goals (Wolters, 2004), or academic self-concept (Valentine et al., 2004) in deed are important prerequisites for achievement, this strategy seems well warranted. Yet, the question remains (a) whether the kinds of motivational regulation strategies students select are successful in this regard (Dresel et al., 2015; Engelschalk et al., 2015, 2016), and whether (b) such a dramatic disregard of cognitive strategies when being confronted with motivational problems would in the end be helpful for learning, given that especially deep processing strategies have been shown to be tightly connected to achievement (e.g., Phan, 2009).

Interestingly, from students' perspectives, comprehension-related problems seemingly do not need to be addressed as specifically (i.e., with an increased focus on cognitive strategies) as motivational problems. Instead, we saw that students also reported a considerable amount of motivational strategies when confronted with comprehension-related problems. In other words, the bandwidth of strategies that students regard as adequate for fixing comprehension-related problems seems to be somewhat broader than that for fixing motivational problems. Such a view is consistent with Boekaerts' (1999) three-layered-model of self-regulated learning which emphasises that the "regulation of the self", which includes the regulation of motivation as a resource for learning, may have an influence on actual information processing (i.e., on the selection of cognitive strategies). Thus, both motivational and cognitive regulation strategies should contribute to achievement. In line with this assumption, Järvenoja et al. (2015) observed that groups often first seem to restore motivation (e.g., by sharing jokes), before they apply cognitive strategies to deal with the learning material.

What we did not find, however, was the three-way-interaction effect we hypothesized: The statistical analysis did not show (a) higher frequencies of cognitive regulation strategies for the situation with simultaneous motivational and comprehension-related problems than in the situation without problems, and (b) than in the situation with only motivational problems. Similarly, we did not observe (c) higher frequencies of motivational regulation strategies in the situation with simultaneous motivational and comprehension-related problems than in the situation without problems, and (d) than in the situation with only comprehension-related problems. One possible reason might be that regulation is always dependent on resources and interactions. From the vignette that described the imaginary group as neither experiencing motivational nor comprehension-related problems, our participants may have inferred that both resources and interactions were very pronounced within the group. Boekaerts (1999), for example, argues that a well-developed knowledge base and high motivation offer a wide range of possibilities for regulation: Learners who know much about the learning topic have a well-developed basis on which to discuss specific aspects of the topic. It is therefore very likely that learners show high engagement in their group activities when they hold conducive motivational and cognitive requirements. The same reasoning may explain why the regulation in the situation with both problems being present was not the highest: Given the fact that the group was described as having low levels of prior knowledge and displaying low learning motivation, our participants might have inferred that the group members have only limited resources to regulate their learning at their disposal. As a result, they might have regarded the group as less capable of taking adequate action to remedy the regulation problems, and thus reported less strategies than expected. This explanation also coincides with the observation regarding the regulation of comprehension-related problems, where participants did not decrease their use of motivational strategies. There, too, maintaining motivational strategies seemed to have been a means of initiating or maintaining regulation at the cognitive level (Boekaerts, 1999), and

it may be argued that learners seem to hold conditional strategy knowledge that pure cognitive regulation is not effective when learning motivation is deficient.

This argumentation would strongly suggest that learners are aware of the value that keeping up motivation has for cognitive regulation. This would also answer why they seem to activate more motivational than cognitive strategies when simultaneous problems occur (as compared to the situation with only one of these problems). This result might point to an inhibitory effect: When both problems are present, students' concentration on fixing the motivational problem might inhibit the active and sensitive regulation of the comprehension-related problem. It would even be conceivable that learners activate a relatively fixed number of strategies for regulation, and that there would be a shift towards motivational strategies in case of an appearance of motivation-related problems. This would be consistent with the descriptive observation that most students actually named similar amounts and only a few strategies per situation.

We were further interested in whether there would be differences in general strategy use at the three social levels of regulation (Research Question *RQ2*). We observed that regulation strategies were significantly more frequent at the self- and the shared-level than at the co-level, which contradicts the findings of Malmberg et al. (2017), who found a dominance of co-regulated activities. A straightforward interpretation of the high amount of strategies at the self-level might be that exams (which we used in our vignettes as a context for the student groups) typically need to be taken by individuals (and not by groups). Focussing on the self-level seems to be a rational choice from this perspective. Also, working together with others to jointly resolve problems that persist in the group (i.e., regulating at the shared-level) seems to be functional in this respect: if the group manages to successfully regulate a joint problem, this will also be of benefit to the individual learner. A further explanation might be that the vignette-based approach made it more difficult to mentally picture the co-learners, especially since the descriptions of the groups did not differentiate between the members of the study group. This, also, might have added to the comparably high frequencies of strategies at the self-level.

Beyond the fact that the vignettes we used did not point to specific group members who might have more motivational or comprehension-related problems than others (and therefore might have made co-regulation more likely), the comparably lower rates of strategies at the co-level may indicate that students (a) might not see much value in helping others to overcome their own regulation problems, or (b) might be overstrained by the regulation of the problems of other group members (Järvenoja & Järvelä, 2009). Also, there might be a social barrier to expose the problems of other group members who already demonstrated that they are not motivated to learn, or have difficulty understanding the subject matter (Hadwin et al., 2018). Given that co-regulating the learning of others (e.g., by providing explanations to group members who have difficulties understanding the learning material) has a tremendous potential to also advance one's own knowledge (e.g., Webb, 1989), students should however be scaffolded to engage in such co-regulation processes. This could be done for example through the provision of collaboration scripts (Schwaighofer et al., 2017), or group awareness tools (Janssen & Bodemer, 2013). Both might be designed in a way that elicits (especially comprehension-related) problems of each single member of a group, e.g., by prompting them to explain what they do not (yet) understand and/or by displaying this information to all members of the group (see Schnaubert & Bodemer, 2022). Yet, further research is needed to reveal the causal mechanisms that are responsible for the low rate of co-regulation we observed in our study.

Limitations and conclusions

Of course, this study is not without limitations. Most importantly, we feel the need to critically examine the pros and cons of the vignette-based approach we have taken. We chose this methodological approach for four reasons: First, it allowed us to experimentally manipulate the kinds of situations we were interested in, which gave us the opportunity to arrive at causal statements regarding how different kinds of regulation problems may impact regulation behaviour in study groups (Janssen & Kollar, 2021). Second, asking students to report how they would act in an imaginary situation is more economical than having groups work together for a more or less extensive time and analysing their group processes. Third, it is a well-known problem that many regulation strategies, particularly those at the self-level, do not materialize in group interaction, even though they might be used. In other words, many strategies are executed at the (invisible) cognitive as opposed to an observable, behavioral level (Hadwin & Järvelä, 2011). And fourth, since we were interested in assessing students' conditional strategy knowledge rather than their actual behavior, the vignette-based approach seemed to be more valid than looking at real collaboration processes. Yet, our decision to use case vignettes and to ask participants how they would react left us with (a) subjective (rather than objective) data on regulation processes that, furthermore, (b) only referred to hypothetical instead of real group learning situations. Thus, we do not know whether students would apply the strategies they reported also in real situations (Spörer & Brunstein, 2006).

Also, it should be mentioned that the sample size was possibly too small to detect the expected triple interaction[1] (e.g., Bortz & Döring, 2006). In the end, the interaction became apparent in the descriptive statistics. In order to statistically uncover the expected effect, it would be advisable to replicate the study on the basis of a larger sample size.

Without downplaying these limitations, our study provides evidence that the way group members (at least intend to) regulate their own and their groups' learning processes seems to be highly rational as they (a) mainly use motivational regulation strategies when they are confronted with motivational problems (at least when they occur in absence of comprehension-related problems), (b) use both motivational and cognitive regulation strategies when they are confronted with comprehension-related problems, and (c) regulate more at the self- and shared than at the co-level when the goal is to (individually) pass an exam. In this sense, university students seem to hold considerable amounts of conditional strategic knowledge on how to regulate different problems that may emerge during collaboration.

Yet, given that research is replete with evidence that students often have difficulties in effectively regulating their learning (de Bruin & van Merriënboer, 2017), future research should also investigate the *quality* at which students apply these strategies (also at the co- and the shared-level). In other words, it might well be that students hold conditional strategy knowledge that leads them to select the right strategies for the right problems, but fail to apply these strategies effectively. In the longer term, scaffolds could be indispensable (e.g., Azevedo & Hadwin, 2005; Järvenoja et al., 2020; Schwaighofer, et al., 2017) to support an awareness of a high-quality execution of problem-sensitive strategies and to prepare students for effective collaboration.

[1] A power analysis with an alpha level of .05 and a power of .90 revealed that we were able with the current sample of $N = 258$ student to detect moderate effects ($f = .22$).

Beyond possibly informing the design of scaffolds that support groups in regulating their learning processes, we believe that our results have implications for theory-building. First, our results imply that learners may have a more or less shared "script" (Fischer et al., 2013) that guides their decisions regarding how to react to different kinds of problems. For motivational problems, this script seems to say "Increase motivational regulation strategies". For comprehension problems, it seems to say "Keep all kinds of regulation strategies up". When looking at these scripts from a theoretical point of view, they both seem very rational: In the presence of motivational problems, the "Increase motivational regulation strategies" script will help select and apply strategies that directly address this kind of problem. Also, it is clear that other kinds of strategies (such as elaboration strategies or monitoring strategies) are not promising to get rid of motivational problems. In the presence of comprehension problems, a broader set of strategies may however be helpful. For example, in case of low comprehension of the subject matter, increasing motivation may be a first step that will set the foundations for further learning processes. These further learning processes will then have to include and possibly be strongly characterized by the use of cognitive regulation strategies. In other words, motivational regulation strategies (and further kinds of regulation strategies) may help set the floor for an engagement in cognitive regulation strategies; thus, both kinds of strategies have value in solving comprehension problems.

Second, our study points to the need to further develop the concept "sensitivity of strategy use", as assigning cognitive strategies as matching with comprehension-related problems and motivational regulation strategies as matching with motivational regulation problems may be too coarse-grained. In fact, we are currently working on an alternative concept, called "immediacy of strategy use", which explicitly takes the possibility into account that certain regulation problems can also be "immediately" tackled by the use of strategies from other strategy categories (for an in-depth discussion, see Melzner et al., 2020).

Finally, our study implies that the complex skill of learning collaboratively to gain subject matter knowledge (De Backer et al., 2022; Järvelä et al., 2021) requires high levels of metacognition: First, the group needs to notice that there actually is a problem that needs to be regulated. Second, learners need to identify of what kind this problem is. Third, they need to reflect what kinds of strategies they have at their disposal that might help solve the problem. In many instances, all these processes may be executed on a subconscious level. However, there might be instances in which a conscious, in-depth reasoning process is necessary to inform action, and the results of our study suggest that students hold a considerable amount of conditional strategic knowledge and are able to perform such metacognitive processes, at least when it comes to the selection of strategies.

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Author2: Planned the empirical study, supervised during the writing process.
Author3: Planned the empirical study, supervised during the writing process.

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Declarations

Disclosure of potential conflicts of interest The authors declare that they have no conflict of interest.

Research involving human participants and/or animals All procedures performed in the study involving human participants were in accordance with the ethical standards of the institutional and national research committee.

Informed consent In the course of the data collection, the data was collected completely anonymously. In addition, the submission does not include images that may identify the respective participant. Under these circumstances, it was possible to dispense with obtaining informed consent in accordance with the GDPR.

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