The joy of understanding mathematics: How emotions emerge from students' beliefs and social experiences of learning mathematics at university

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Abstract: This paper aims to better understand the interconnectedness of students' emotions, beliefs, and experiences situated in the specific context of university mathematics education. Therefore, interviews with six students from three different universities in Finland and Germany were analysed using a thematic reflexive analysis. The findings identified the distinction between calculating and proving, the role of the subjective experiences of understanding, and the importance of social interactions for emotion regulation as key themes. It will be detailed and discussed how emotions emerge from different beliefs and experiences regarding these themes.

Keywords: emotions, beliefs, social experiences, university mathematics.

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1 Introduction

The transition from secondary to tertiary education in mathematics presents numerous challenges for students (e.g., Gueudet, 2008), often accompanied by strong negative emotions (Di Martino & Gregorio, 2019; Göller & Gildehaus, 2021). Students' affect, comprising beliefs, attitudes, motivation, identity, and emotions, has garnered increasing attention in educational research (Hannula, 2012; Hannula et al., 2019). However, emotions remain a relatively underexplored area, particularly in the context of higher mathematics education (Di Martino & Gregorio, 2019; Göller & Rück, 2022).

The differences between secondary and university mathematics pose significant epistemic challenges that can lead to what has been termed a "beliefs overhang" (Daskalogianni & Simpson, 2001). Such challenges often result in student disengagement, manifesting as feelings of alienation, a lack of sense of belonging, or positioning oneself as an outsider within the academic community (Gildehaus et al., 2024; Lahdenperä & Nieminen, 2020; Solomon & Croft, 2016). Affective variables have been linked to academic outcomes, including exam performance, study satisfaction, and study dropout (Benden & Lauermann, 2023; Geisler, 2023; Göller &

Gildehaus, 2024). They are intricately tied to the emotions students experience while engaging with mathematics at the university level (Göller & Gildehaus, 2021; Göller & Rück, 2022; Lahdenperä et al., 2024).

The emergence of emotions in academic settings is often theoretically explained by appraisal theories (Ellsworth, 2013; Moors, 2020; Scherer, 2019). The core idea of appraisal theories is that emotions are generated through an individual's evaluation (i.e., their appraisal) of a situation or event, particularly in relation to personal goals, values, and beliefs. These appraisals then determine how individuals perceive and respond emotionally to the specific event (Ellsworth, 2013; Moors, 2020; Scherer, 2019). For example, Pekrun's (2024) Control-Value Theory explains emotions in academic contexts through control-value appraisals, which means that students' emotions are influenced by their perceptions of control over their academic outcomes and the value they assign to those outcomes. Specifically, when students perceive that they have control over their academic success and value the task at hand, they are more likely to experience positive emotions such as enjoyment or pride. Conversely, low control and low value can lead to negative emotions like anxiety and hopelessness (Pekrun, 2024).

However, although these theories hint that such appraisals build on, for example, cultural contexts or social environments, they do not delve deeply into how and on what basis such appraisals arise in specific social contexts, such as mathematics education. Accordingly, the aim of the present contribution is to better understand the emergence of emotions and the underlying appraisals through the interplay of students' beliefs and experiences in a given social environment, especially in the sociocultural context of university mathematics education. This perspective will be introduced theoretically in the next section, followed by an empirical study situating these ideas in university mathematics education.

2 Theory

The theoretical framework guiding this study on mathematics-related emotions is heavily influenced by the work of Op't Eynde et al. (2004; 2006a, 2006b). Learning is conceptualised as a form of engagement that allows students to actualise their identities by participating in activities within a specific context (Op't Eynde et al., 2006a). This perspective emphasises that students are continually challenged to reconcile their past experiences with their current experiences, which are understood as their individual perceptions of a particular situation, here in the university

mathematics learning environment. By participating and engaging within this social environment, they derive meaning and potentially renegotiate or reconstruct their understanding (Op't Eynde, 2004).

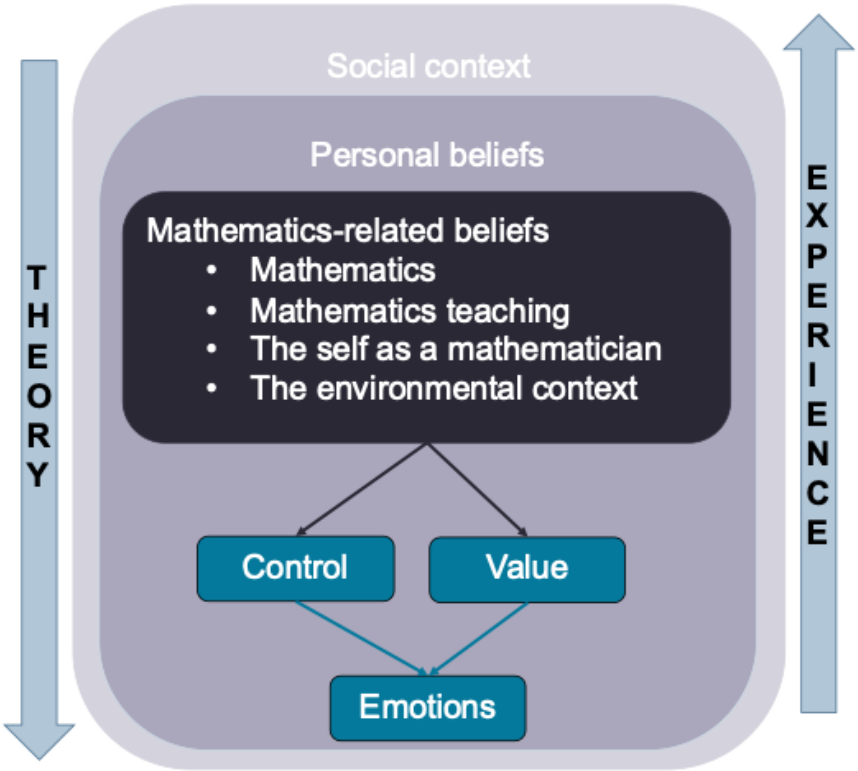
Students' past experiences are thought to be encapsulated in their beliefs, which are defined as the subjective conceptions they hold to be true, whether explicitly or implicitly (Op't Eynde et al., 2006b; Philipp, 2007). These mathematics-related beliefs can pertain to various facets, including the *nature of mathematics*, *mathematics teaching and learning*, the *self-perception as a mathematician*, or the *environmental context* with its socio-mathematical norms and the roles of the self and others in this environment (Op't Eynde et al., 2006b). Through their personal relationships towards these beliefs, students assign value to different aspects of mathematics and mathematics education they experience, reflecting their preferences and expectations regarding the role of teachers and the nature of mathematical knowledge. For example, some students may emphasise instrumental/static aspects of mathematics, such as rule application and procedural correctness, while others may prioritise relational/dynamic aspects, focusing on understanding the underlying principles and engaging with mathematical problems (Di Martino & Zan, 2010; Gildehaus et al., 2024; Göller, 2023). Such beliefs are considered lenses that shape individuals' views, perceptions, and dispositions toward action (Op't Eynde, 2004; Philipp, 2007). Accordingly, students' beliefs are hypothesised to heavily influence their current experiences and, in turn, their appraisals in a specific situation, from which, in line with appraisal theories, their emotions emerge. This theoretical direction is visualised in Figure 1, read from top to bottom.

However, as beliefs can be implicit as well as explicit, individuals may not always possess clear insights into their personal beliefs. Often, the significance of their actions and values becomes apparent only in the context of specific situations (Op't Eynde, 2004). In this situation, students' emotions reveal and make them aware of their values and beliefs (Op't Eynde et al., 2006a). Emotions are considered an integral part of participation in particular practices of a social environment, and mirror alignment, clashes, or tensions of experiences and beliefs (Op't Eynde et al., 2006a). This direction of experiences is visualised in Figure 1, read from bottom to top.

Therefore, to better understand emotions such as, for example, joy or frustration as they arise in context, it seems fruitful to analyse joyful or frustrating situations in the social environment (Op't Eynde, 2004), seeking alignment, clashes, or tensions of

individual beliefs and current experiences. This will be done in the following, focusing on the context of university mathematics, yet in very different social environments.

Figure 1. Visualisation of the theoretical framework



2.1 Aims and research question

This paper aims to better understand the interconnectedness of students' emotions, beliefs, and current experiences situated in the specific context of university mathematics education. To do so, we aim to abstract from singular appearances bound to specific situations by analysing data from different institutional settings, with the following research question: How do students' emotions in university mathematics education emerge from the alignment, clashes, or tensions between their mathematics-related beliefs and current experiences?

3 Methods

3.1 Context, sample, and data collection

To answer our research question, we analysed interview data from six different first-year students across three distinct universities (one in Finland and two in Germany)

that provided different institutional contexts. The Finnish university context involved a five-credit proof-based Linear Algebra and Matrices course. This course was implemented with Extreme Apprenticeship ("innovative"), combining inquiry-based mathematics education with a flipped learning approach (Rämö et al., 2021). New topics were introduced by introductory exercises, which were submitted by students who then attended lectures that were based on their discussions and focused on the main contents and their connections. After the lectures, the students solved more challenging problems and a new set of introductory exercises for the next topic. To support students, guidance was offered in an open learning space for several hours a day. Students received bonus points for completing the exercises, which counted toward the final exam that had to be passed for the course.

In the first German university ("traditional"), students could attend nine-credit proof-based Linear Algebra or Analysis courses consisting of lectures (twice a week) where mathematical theory (i.e., definitions, examples, theorems, and their proofs) was presented by the lecturer mainly on the chalkboard, and exercises were handed out every week. Students had to work on these exercises in self-study (homework) and submit their solutions, which were then corrected, graded, and discussed in a small group tutorial. To pass such a course, 50% of the points for the exercises must have been achieved (to be admitted to the exam), and a written examination had to be passed.

The institutional context of the second German university was similar to the setting of the first German university regarding the organisation of lectures, exercises, and examinations. However, due to the COVID-19 pandemic, the course was held online weekly in a face-to-face setting ("online"). Additionally, students were recommended to work through additional resources (e.g., self-made videos or other videos on the web) themselves and to prepare questions for the lecture. Students were offered a weekly full-class tutorial in which solutions to the previous week's homework were presented online, and small-group tutorials in which further tasks to prepare for the homework were discussed. Neither lecture nor tutorials were recorded. Additionally, students could drop into an online mathematics learning support centre to ask tutors additional questions, for example, about homework. Students had to reach 50 % of the points on the weekly exercises to be admitted to the final exam.

The interview data stemmed from three different research projects (Gildehaus, 2024; Göller, 2020; Lahdenperä, 2022) situated in these three contexts with different research foci. However, the interviews shared commonalities, as outlined below. At

the time of the analysed interviews, all six students were enrolled in one of the courses on theorem-proof-based Linear Algebra or Analysis and had already participated in at least one mathematics examination at university. Each interview included questions about the students' recent study habits in their mathematics courses, including their goals, motivation, beliefs, and learning approaches. Emotions were not explicitly addressed in these interviews; students expressed them freely without direct guidance from the interviewers. Each interview was conducted by one of the three authors, lasted approximately one hour, and was transcribed verbatim. The interviewed students provided active consent for the scientific analysis of their data and the publication of anonymised quotations.

The sample for this study comprises two students from each of the three institutional contexts and was chosen based on the variety of emotions reported in the interviews. Mathematics majors Lumi and Kuura both studied in the Finnish innovative teaching setting. Jordan, a mathematics major, and Alex, a higher secondary preservice teacher with mathematics as one of two (compulsory) subjects, both studied at the German traditional teaching setting. Andrea and Kim were both higher secondary preservice teachers with mathematics as one of two (compulsory) subjects, studying in the German online teaching setting. We use gender-neutral names, as gender is not the focus here.

3.2. Data analysis

Following the considerations in the theory (cf. Op't Eynde, 2004) as a first step, each author screened their interview data for words indicating positive (e.g., good, like, great) or negative (e.g., bad, annoying, stupid) appraisals as well as positive (fun, happy, (en)joy) or negative (e.g., frustrating, depressing, no fun) emotions and translated the associated passages into English. In the second step, we used these fully anonymised passages and reflexive thematic analysis (Braun & Clarke, 2021) to generate, develop, and refine themes focusing on underlying beliefs and experiences in the social environment of university mathematics. This analysis was guided by our theoretical assumptions, meaning that we started from emotional expressions and then actively searched the surrounding data for referring narrated experiences and beliefs, aiming to understand the occurrence of these emotions in terms of alignment, clashes, or tensions between different facets of beliefs and experiences. This led to our initial themes, which were then further refined. The findings given below represent the current state of our analysis and are considered preliminary.

4 Findings

In the following, we organise our findings on how emotions in university mathematics education emerged from alignment, clashes, or tensions of their mathematics-related beliefs and experiences, along with the different facets of mathematics-related beliefs derived from the literature. Indeed, these different mathematics-related beliefs emerged as key in our reflexive thematic analysis. However, and this is a central finding of the study, they are not as separate as the presentation in the following might suggest; rather, they are deeply interconnected. In particular, beliefs about teaching and learning of mathematics and the social context are highly intertwined and will be presented jointly in section 4.3.

4.1 Emotions emerging from beliefs about the nature of mathematics: The difference between calculating and proving

Regarding beliefs about the nature of mathematics, the distinction between "calculating" and "proving" was particularly prominent among the German students in the sample. While for some students (Alex, Andrea, Kim) it was rather calculating that was associated with positive emotions (e.g., Kim: "It's more these calculation tasks that give me joy"), others rather highlighted aspects related to the deductive-proofing nature of university mathematics, like its precision, as highlighted in the following quote of Jordan:

> Jordan: [...] it's often very imprecise at school. But this precision is exactly why I started studying math, and now I can see that it's even more precise. And I'm even happier about it. Because I just see that in philosophy, too. Everything is always so undefined; it could either be this or that, or something. And that really gets on my nerves. I can't stand that at all. And that was the reason why I simply decided to study math. Because I think there's no subject that's as precise and exact and as clear as mathematics. In physics alone, there's always this not-quite-exact, always these fluctuations and stuff like that. And that really gets on my nerves. I can't stand that at all. I totally hate that. And I still love that about mathematics, actually. And I've always loved analysis, with functions and stuff. I still love analysis. As you can see, I just like math.

As indicated in this quote from Jordan, such beliefs about different aspects of mathematics can be associated with very strong emotions (here, for example, Jordan: "I still love analysis"), depending on their alignment with experiences made in the social context. The quote also indicates that Jordan's emotions could be the opposite if mathematics were not experienced with that precision (Jordan: "I totally hate

that"). In contrast, Alex, who associated calculating with positive (Alex: "Gauss [algorithm], that's fun if you can calculate a bit") and proofing with negative emotions, experienced studying mathematics very differently:

> Alex: [In linear algebra] it was mainly proofs, that's something I can't stand, I don't need it somehow, it's pointless for me. Because moving letters around is not really my thing.
>
> Interviewer: Well, that's just the question of whether proofing is a matter of moving letters around? Is that so?
>
> Alex: Yes, I kind of see it that way, because I don't know. I just think it's pointless, you can't really do anything with it.

As the courses investigated in this study were all proof-based, students with beliefs more aligned with proofing described rather positive emotions, while students with beliefs aligned with calculating described rather negative emotions. However, Kuura offered another stance. Despite experiencing feelings of confusion about proofs (Kuura: "especially proofs […], like where did this thing come from […] and what is happening here"), they stated:

> Kuura: In mathematics, you need to truly understand what's going on. And if you readily get an answer to a task, then you haven't necessarily understood what was happening in the […] proof […]. So, it doesn't develop your own competence at all. And it is of utmost importance […] on first-year courses to get some kind of basic knowledge and develop your mathematical thinking. And it doesn't develop through ready-made answers.

4.2 Emotions emerging from beliefs about the self as a mathematician: The role of the subjective experience of understanding

The two quotes from Jordan and Alex in the previous section explain how emotion can emerge from the interplay between beliefs about the nature of mathematics and the mathematics experienced in a given setting. However, they additionally indicate a specific way of participation of Jordan and Alex in the university mathematics environment. While Jordan was fully involved and identified with mathematics at university, Alex appeared alienated from it. This interpretation is supported by other parts of the interview where Alex describes university mathematics as "strange" or "weird", while the involvement of Jordan appears to come from a turning point ("click moment"), as described in the following quote:

> Jordan: I think that Christmas was one of those click moments. Before Christmas, I was so incredibly desperate. […] I think that was the moment when I realised: You're not at school here anymore. So, you realised that this no longer had much to do with school math, you should really strip it all away. I think that was the moment when you could best get involved with the mathematics that takes place here at the university, somehow. And that was kind of strange, because I hit such a low point before Christmas; it was really beyond a joke. I was really thinking, should I keep doing this? I can't get this shit together. But I also didn't know what else to do […]. And I wanted to show everyone who said I couldn't do math, I admit that, too. They all annoyed me so much. […] Then I said [to myself]: No, you go on now. And then suddenly it started, so that I slowly understood more and more. And somehow got better at the exercises and so on. And that kind of gave me a boost forward.

We want to highlight at least the following three parts of this quote: First, it appears that Jordan could "best get involved" with university mathematics when detaching from school mathematics ("strip it all away"), combined with the personal mission "to show everyone who said I couldn't do math". All three preservice teachers highlighted their belief that they would not need university mathematics, and especially proofs, for their future teaching profession, as indicated in the following quote:

> Andrea: You know you'll never need it again. And yes. So, when someone asks me how my studies are going, I always say, it's no fun now, but it has to be like this, right?

From Jordan's quote, it appears that Jordan's involvement and engagement with university mathematics stems from the belief that they had no other choice but getting involved (Jordan: "I also didn't know what else to do"), while the belief that preservice teachers would not need university mathematics seems to impede their participation with positive emotions and kept them from detaching from school mathematics and normalizing negative emotions (Andrea: "it's no fun now, but it has to be like this, right?").

Second, although the outcome that Jordan "understood more and more" might address the cognitive level, Jordan traced it back to a "click moment" on the affective level, particularly in beliefs. Nevertheless, third, Jordan's quote highlights the importance of the subjective experience of understanding for positive emotions and the absence of such subjective experiences of understanding for negative emotions, which was apparent in all interviews. The following quote from Kim indicates how such subjective experiences of understanding can contribute to positive emotions and

also overcome emotions emerging from beliefs about the nature of mathematics as presented in section 4.1:

> Kim: That's why it's more these calculation problems that give me pleasure. Although I do remember one situation. I created a kind of mind map for this linear algebra exam, where I linked all the individual definitions and theorems together and connected them with lines. And in the end, it looked quite confused, but somehow it made me proud, and I was pleased with it. Okay. I now have understood the connections and somehow managed to put them on paper in a summarised form. And then I really had a little moment where I thought, wow, I've understood totally complex things. […] And I'm missing that a bit this semester because I haven't had the time or the muse to somehow try to make all these connections clear to me, because I thought that helped a lot with my studies. And since that's very lacking at the moment and everything seems incoherent to me, I'm not really enjoying it at the moment.

We would like to highlight the meaning of each word in the phrase "subjective experiences of understanding". Understanding emerges as an experience of coherence in a specific situation. This experience is subjective in nature and relies on individual beliefs about what understanding means in this specific situation and context. The importance of this subjectivity is also expressed in the following quote from Andrea:

> Andrea: Well, I wouldn't identify more with math if I got better grades on the exams. That has nothing to do with it for me. That doesn't contribute to whether I identify more with it or not, but rather the understanding. So that you have fun with it. Yes. Not grades, but rather fun, I would say.

4.3 Emotions emerging from beliefs about the teaching and learning of mathematics and the social context: The role of social interactions

This subjective experience of understanding is co-regulated by the social environment, potentially leading to reappraisals of specific situations according to their value experienced in social interaction.

> Andrea: So maybe one of the tasks on this exercise sheet has something to do with calculations, so that you can somehow create that joy again […]. Yesterday morning, I thought I'd had the moment of my life because I'd made an equal sign in this proof. And then [name] said: "Yes, I knew that from the start." And then I thought again, oh shit. That wasn't a moment of joy. But in the end, I was kind of happy. So sometimes it's fun. When it works, then you have a moment of joy. So yes. But it's just rare.

Again, we find the general preference for calculations. However, the subjective experience of understanding (Andrea: “I’d made an equal sign in this proof”) leads to a moment of exuberant joy (Andrea: “I’d had the moment of my life”) that is diminished or even reversed by the other student’s comment that “I knew that from the start.” Theoretically, this quote indicates how joy emerges from the experience of having accomplished something that is believed to be highly valued in the social context, and how this joy is degraded by experiencing that it is not as highly valued as believed. Still, the quote highlights the importance of the subjective experience of understanding for positive emotions, although not socially valued as highly as believed in this case (Andrea: “But in the end, I was kind of happy”).

Mostly, this social co-regulation of emotions was present in the interviews in a rather positive way, by leading to relief in giving context to individual beliefs.

> Kim: So there have been a few situations where I’ve sat here and had tears in my eyes, or was totally desperate because I just couldn’t understand anything. And then, somehow, a message came into our group like this: “Yes. Somehow, I’m totally shit right now too. I can’t understand anything here, and I’m totally desperate.” Then you know, okay, I’m not the only one. And I think that would be totally missing if you didn’t have this learning group.

The experience that “I’m not the only one” here gave context for beliefs about norms regarding the subjective experience of understanding, which then created a basis for interpreting future subjective experiences of understanding.

> Lumi: I sat next to one of my course friends [in the lectures] and we like shared this feeling, we were just confused, like we didn’t understand. It was also kind of therapeutical, like there was someone else who doesn’t understand. And then we then together tried to create the basis for understanding, like what is going on here. It was great to discuss the matters.

Beyond individual beliefs, all analysed students shared the beliefs about the importance of supportive social interactions and discursive participation for learning mathematics, accompanied by positive emotions if experienced

> Lumi: It has increased my enthusiasm towards mathematics, like it has been great […]. It has been a positive surprise. […] In high school, I had six different maths teachers, and I got a kind of cross-section of teaching. And when I came here [to the university], I thought that the lecturer would have their back towards the auditorium, and then you write until your hand dies. I was prepared for that, and then I got something completely different. I’m maybe like happy and positively surprised, this is like fun, I’ve had many of these experiences.

and accompanied by negative emotions if not:

> Alex: And in the tutorials, I somehow always have one-on-one conversations with the tutor because the others don't feel like it or leave halfway through or right at the beginning. And when I ask a question, they moan in the back the whole time.
>
> Interviewer: Really?
>
> Alex: Yes, it's really annoying that you can't ask a question, and then there's moaning right away. If they're not interested, then they should leave. I thought the exercises were actually there so that you could ask questions.

5 Discussion

To better understand the interconnectedness of students' emotions, beliefs, and experiences situated in the specific context of university mathematics education, we analysed interview data of six students with mathematics as a study subject in three different social environments. As a first theme, the reflexive thematic analysis revealed the distinction between calculating and proving as one key for understanding the emergence of emotions from alignment or tensions of students' instrumental/static or relational/dynamic beliefs about the nature of mathematics (Di Martino & Zan, 2010; Gildehaus et al., 2024; Göller, 2023) with their current experiences in the context of university mathematics education. As a second theme, the role of the subjective experiences of understanding was identified with the potential to overcome possible negative emotions based on instrumental/static beliefs from the first theme. Finally, the third theme highlighted the importance of social interactions for emotion regulation by providing social support and comparisons for possible reappraisals of students' experiences.

These findings contribute to theory building situated in mathematics education by specifying the role of students' mathematics-specific beliefs and situated experiences for their appraisal processes that influence emotions (Ellsworth, 2013; Moors, 2020; Pekrun, 2024; Scherer, 2019). Practically, the findings highlight the importance of support structures for meaningful mathematics-related social interactions to foster students' subjective experiences of understanding in university mathematics learning environments for positive emotions and for preventing disengagement, feelings of alienation, a lack of sense of belonging, or the positioning oneself as an outsider within the academic community (Gildehaus et al., 2024; Lahdenperä & Nieminen, 2020; Solomon & Croft, 2016). Preservice teachers' instrumental/static beliefs about the

nature of mathematics (Göller, 2023), with their focus on calculations and the perspective of their future profession, may hinder getting involved with university mathematics and detaching from school mathematics as Jordan did. Therefore, especially in teacher education, fostering subjective experiences of understanding and positive social interactions appears crucial for enabling meaningful participation and emotional well-being.

This study is subject to several limitations, including the small sample size, reliance on secondary data, and the absence of direct questions about emotions. Nevertheless, the theoretical perspective (Op't Eynde, 2004; Op't Eynde et al., 2006a, 2006b) of this paper proved to be very fruitful for better understanding the emergence of emotions in social environments based on students' beliefs and current experiences, which is highly desirable to be further investigated in future studies.

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