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Abstract

The growing integration of technology into education, particularly in the STEM fields, has tended to focus on its objective advantages, ignoring its affective potential. To explore this potential, based on some principles of *Kansei/Affective Engineering*, an initial analysis was conducted considering 501 interventions in a conversation among six students about a previous e-learning experience. The analysis revealed the need for personalized feedback, a self-adapted pace, and the possibility to express. Based on the identified needs, three activities (*applets* based on *dynamic reasoning* and contextualized in the movement of the Sun) were designed to explore the *affective value* of the tool through the feedback it provided. Thirteen engineering students at a Japanese university participated in the experiment and the results were analyzed considering the type (*task-focus/constructivist*, *self-focus/motivational*) and purpose of the feedback, as well as some indicators based on the *Instructional Feedback Orientation Scale*. The model constructed for each student revealed that those who attributed a higher value to feedback showed a greater relation between the purpose of the feedback received and the reaction selected (*completion*-positive, *correction*-negative). Furthermore, it was found that the proposed model can inform future designs based on the potential of the feedback to promote positive reactions.

Introduction

Recently, technology has been increasingly integrated into education, especially due to the current pandemic, with the implementation of hybrid and online modalities. Although these modalities have advantages for asynchronous learning and to activate students as the owners of their own learning (Burns et al., 2020), the implementation has often focused on the objective values of the tool, ignoring its affective potential. Within the STEM (Science, Technology, Engineering and Mathematics) fields, particularly in initiatives from mathematics education, the common assumption of mathematics being a discipline devoid of emotions, has emphasized a focus on the objective, although "it has been widely acknowledged that mathematical thinking is not purely logical reasoning, but influenced much by affective features" (Hannula, 2020, p. 32). In this sense, Nava Guzmán et al. (2021) suggest identifying the emotions that students experience when they try to employ *covariational reasoning* (essential in the STEM fields), as this would allow the identification of the type of activities that may promote a stable emotional environment for learning.

In line with the above, the objective of the present research is to explore such emotions based on the feedback provided, as ample studies indicate that *feedback* as a stimulus has a more powerful impact on learning than any other variable, and as a set of practices geared for learning and closely linked with assessment, is an inherently emotional interaction that can have long-lasting impact (Molloy et al., 2012).

Previous Research

STEM Education

Interest in interdisciplinary approaches to mathematics education has increased in recent years, especially within the fields of STEM. One of the reasons behind the increase is a demand for more engaging learning environments, either based on how content is addressed or how it is delivered.

Contextual Significance in Mathematics Education

Regarding how content is addressed, the epistemological background shared by physics and mathematics has inspired the creation of several activities integrating both disciplines. Particularly in the case of calculus, the physical notion of *flow*, as in the Newtonian notion of the continuous flow of time (Arthur, 1995), can facilitate a dynamic analysis of the mathematics of change and variation. In this sense, context can become an enabler if it provides a phenomenological approach congruent with the mathematics addressed, and a way to assess such congruence is through the type of reasoning involved. Keene (2007) defines for this a *dynamic reasoning* as one that complements and uses other types of reasoning, including *covariational reasoning* and *graphical reasoning*.

Covariational reasoning refers to "reasoning about values of two or more quantities varying simultaneously" (Thompson & Carlson, 2017, p. 423), while graphical reasoning focuses on graphical mathematics. According to Kaput and Roschelle (2013), as graphical mathematics needs to be part of the basic mainstream experience for all students, a major step in that direction will require moving from static graphs (merely read and interpreted) to dynamically manipulable graphs that can be linked to phenomena and simulations. A digital learning environment can provide such space if both its *pragmatic* and *epistemic* values are considered. In the field of Mathematics Education, Artigue (2002) introduced these concepts to discuss the role of technology when learning mathematics, arguing that instrumented techniques are most often perceived and evaluated in terms of their *pragmatic value* by focusing on their productive potential (e.g., efficiency or cost), but that they can also have an *epistemic value*, as they may contribute to the understanding of the objects they involve, becoming a source of questions about the mathematical knowledge addressed.

Adaptive Learning

Regarding how content is delivered, besides the objective values mentioned, another concern that has recently come to the forefront is the need to also consider the subjective. In the field of educational technologies, a common approach to this issue has been the creation of adaptive learning systems, as they can involve both cognitive and affective aspects in their development. Hwang et al. (2020) explored this approach by creating a system that analyzed students' affective status and their knowledge level to deliver personalized mathematics learning materials. As for the affective aspect, the system would show short answer questions to arouse the student's concentration; a tip or a reminder to take a rest if a student's learning time was higher than the average; or even a joke to encourage learning willingness.

Another approach, followed by Grossman et al. (2019), was based on creating a conversational experience by mimicking some facets of conversation with a human tutor, namely conversational flow, comprehension checks, and personalized feedback and guidance. The system created for this purpose (*MathBot*) explained math concepts and provided practice questions, while offering tailored feedback. To express this feedback, it is reported that the system used a friendly tone and provided supportive cues such as transition phrases and emojis, especially when delivering feedback indicating correct or incorrect responses.

As can be noted in both studies, feedback emerges as a key factor to address affect in the design of adaptive learning environments. Particularly, the potential use of educational technologies for asynchronous e-learning allows devising strategies to enhance flexible, constructive, and formative learning for students both on and off campus, as it has been shown that this type of e-learning can lead to improvements in summative examination outcomes, and activate students as the owners of their own learning (Burns et al., 2020).

Affect and Education

To explore what students experience when using educational technologies, some researchers propose creating students' profiles. With this approach, Muñoz et al. (2016) point out that *student modeling* has recently focused on affect, as it has been shown to influence students' understanding, performance, and motivation.

Epistemic Emotions

Within educational research, Chevrier et al. (2019) evaluated a model that proposed relations between *epistemic cognition*, *epistemic emotions*, and *self-regulatory strategies* when learning complex contradictory content. Based on this model, they found that more constructivist beliefs about the complexity, uncertainty and justification of knowledge predicted more *curiosity*, and that curiosity, among other epistemic emotions, was the most significant predictor of self-regulated learning strategies.

In addition to these findings, the need to promote an emotional stability within learning environments becomes especially relevant when considering the case of women studying in STEM-related fields, as they may experience a "chilly climate" that lacks social support for women, contributing to their sense of isolation, and having a hard time coping with failures and setbacks because of a sudden loss of belief in their own effectiveness, even among high-achieving women (Kijima et al., 2021). The latter also holds true among males, as it has been shown that, in general, high performers tend to be overly critical and to underrate their performance when compared to external, more experienced judges (Molloy et al., 2012). These results support the necessity of giving feedback a more central role in the design of adaptive learning environments to address the affective component.

Feedback and Emotions

To be explicit about how feedback is conceptualized, Dawson et al. (2018) recommend to first identify what the purpose of feedback is meant to be, then what information needs to be conveyed, and lastly what effects should be monitored. As for the purpose of the feedback, Lam et al. (2011) suggest that it should comprise not only a result, but also a cue for improvement. Regarding what needs to be conveyed, as has been discussed so far, both the objective and the subjective should be taken into consideration. With respect to the subjective, just as the definition of feedback tends to be obviated, its affective component also tends to be ambiguously alluded to in the literature, usually being referred to with broad terms such as *positive* (Hannula, 2020), *encouraging* (Hwang et al., 2020), or *emotional (Cabestrero et al., 2018).*

Concerning what effects of feedback should be monitored, a review of the literature shows that its effectiveness is usually evaluated based on the learning outcomes, or by the students at the end of the interaction. However, the former process may leave the affective component out of the evaluation, while the latter may hinder the evaluation of specific types of feedback. For example, although in the study of Muñoz et al. (2016) feedback can be evaluated by students during the activity, the feedback addressed is not explicitly described, nor how its affective component was considered. Alternatively, whereas in the study of Grawemeyer et al. (2016, 2017) affect is taken into account, it is alluded to only in its encouraging sense as in *affect boosts* or *affirmation prompts*, and the affective content in other types of feedback is not described.

These observations reveal a research opportunity in feedback design, namely, exploring the affective component of feedback in digital learning environments. For this exploration, two theories provide a framework to design feedback considering its affective component, *Attribution Theory* and *Feedback Intervention Theory* (FIT). Based on Attribution Theory, Rajendran et al. (2019) suggest praising the student's effort and showing empathy to create and display the motivational messages. More specifically, when designing feedback, they propose to attribute failure to external factors, to praise the students' effort instead of the outcome, and to make the student feel that s/he is not alone in that affective state.

In contrast, according to Feedback Intervention Theory (King, 2016), feedback can be detrimental to learning when feedback is framed on the *self-level* (i.e., how good am I?) rather than on the *task-level* (i.e., how do I improve?). Thus, for feedback design, this theory proposes to focus on features requiring improvement, directing the locus of attention toward the task, and using face threat mitigation tactics. In line with this perspective, and consistent with the result of Chevrier et al. (2019) regarding students' constructivist beliefs, the success of feedback may depend on the individual's self-image, including their view of their capacity to change. So a central objective may be to help learners to accept their own ability to change and therefore at the same time reduce the threat to self-image and self-esteem (Molloy et al., 2012, p. 58).

By supporting these changes, the affective component of feedback may go beyond a "Well done!" and, in this sense, feedback can be seen as a process of communication (Higgins et al., 2001) where objective and subjective information merge to enhance learning.

Affective Engineering

According to Adelabu and Yamanaka (2014), "the task of design practice now lies in the need to balance objective and subjective properties, functional technology and emotional expressiveness, information and inspiration" (p. 93). This conclusion comes from the perspective of *Kansei*/Affective Engineering, which according to the same authors has an interdisciplinary nature. This nature allows a variety of approaches when it comes to design but, particularly in the design of digital learning environments, it allows a blend between affective engineering and mathematics education.

Towards a Definition of Affective Value in Educational Technology

Previously, the concepts of *pragmatic value* and *epistemic value* were introduced relating to the integration of technology in mathematics education. As these concepts proposed by Artigue (2002) refer mainly to the objective component of the integration, a need arises to consider an *affective value* as well. Such value may comprise from the aesthetic properties of the environment to the epistemic emotions that students can experience from their interaction with the system. As mentioned in the previous section, research in this area has focused on *student modeling*, either by relying on self-reports (e.g., Muñoz et al., 2016), by evaluating contextual variables (e.g. Hwang et al., 2020), or by using coding schemes (e.g., Chevrier et al., 2019).

In Kansei Engineering methodology, an initial exploration of this issue can combine the first and the last of the aforementioned approaches through the selection of appropriate words related to the emotions of the students (Chuah et al., 2008). Particularly, for the research reported herein, an analysis based on this approach was conducted to explore what students find relevant for enhancing an e-learning experience.

Method

Identification of Students' Needs

To identify what students find relevant for enhancing e-learning experiences, a conversation among six participants (three female and three male first year university students) of a similar study (Carranza-Rogerio, 2019) was analyzed. It is noteworthy that although the students were asked to discuss about *what* was being taught, they ended up discussing *how* it was being taught, arguing that how they felt was even more important.

In total, 501 interventions were analyzed, of which 96 were related to emotions. These emotion-related interventions were then classified into five categories; in ascending order of the number of interventions, these categories were *assumed intentions*, *personal description*, *surprise*, *confusion*, and *enjoyment/displeasure*. The category of *assumed intentions* emerged as a few students perceived that some items were designed to confuse them or to make them fall for them; in particular, they referred to occasions when a previously asked question appeared again reformulated. Although the objective of these questions is mainly to consolidate knowledge, students felt that the intention was to make them err. Considering this aspect, feedback can be designed to alleviate the possible arousal of such feeling by considering its affective component.

On the *personal description* category, some self-assessment comments were expressed. Particularly, one student referred to his lack of knowledge, while another student expressed that some parts of the design made her feel underestimated. These contrasting experiences were heightened as no personalized feedback was provided by the system they interacted with; therefore, a need for an adaptive learning system arises. About *surprise* and *confusion*, the interventions were mainly centered on the physical situation (regarding how their previous knowledge in physics was confronted), and the generality of the feedback that appeared after each activity. While the former situation is desirable as it can lead to curiosity (which in turn can predict self-regulated learning strategies as previously described), the latter needs to be addressed through feedback design.

Finally, regarding what students *enjoyed* about the activities, they highlighted the possibility of discovery through visualization, the use of colors to distinguish properties, and the interactivity of the simulations presented. These characteristics are aligned with the need to foster *graphical reasoning*, and to consider the *epistemic value* of the dynamic environment being used. As for the aspects that caused students *displeasure*, they emphasized the absence of personal monitoring (as they were presented with linearly structured activities and lack of personalized feedback), and the impossibility to express themselves (e.g., when they already knew an answer). In conclusion, the needs identified to enhance an e-learning experience of this nature can be condensed into three: the needs to monitoring (with personalized affective feedback), a self-adapted pace, and to express themselves.

Experiment

Considering the identified needs, and with the objective of modeling the affective response of students to feedback in STEM education e-learning activities, three applets were developed considering the *pragmatic*, *epistemic* and *affective values* of the environment. Firstly, born from the necessity to contextualize mathematics in a meaningful way, a physical phenomenon was selected. This selection also responded to the results of Chevrier et al. (2019), as they found evidence for the arousal of epistemic emotions when learning from complex and *contradictory* learning material. The phenomenon selected was the motion of the sun throughout a year, as it allows a *dynamic reasoning* about the mathematical variables involved; and its *contradictory* quality was based on how this phenomenon is usually assumed as common knowledge, yet it has been shown to be challenging for students.

According to Anantasook et al. (2015), the challenges for understanding celestial motion include that (1) students have limited experience of observing the change in location of the sun; (2) the apparent motion occurs so slowly that it is imperceptible by a single direct observation; and (3) the difficulty to accurately represent the appearance of objects in the three-dimensional sky. These challenges were addressed in the activities starting with an exploration, then creating a model, and concluding with an application. Each activity focused on specific elements of the process, which can be seen in Table 1.

As previously stated, *dynamic reasoning* can be complemented by *covariational* and *graphical reasoning*, and these types of reasoning can be enhanced with a congruent environment. For this purpose, the environment selected was GeoGebra, which is an application (freeware with open-source portions) with an online platform where the material based on its software can be shared. This application has been known for its potential to create dynamic manipulable graphs, yet it usually requires the direct guidance of a teacher; otherwise, it relies on the description attached to the applets, which might not be enough guidance, especially for asynchronous learning. To overcome this issue, considering the benefits of creating a conversational experience (Grossman et al., 2019), the activities (applets) developed for the experiment consisted of a dialogue area along with an interactive graphic area (left and right side of Figure 1, respectively).

Table 1. Main Elements of Each Activity

	Elements
Activity I *Exploration*	P0: *What do you think mainly causes the seasons throughout a year? (Answer options appear in Figure 2.)* P6: *In the Northern Hemisphere, when would it be summer? (Considering the position of the Earth relative to the Sun with an interactive simulation.)* P16: *Use the sliders (of date and time) to explore the amount of sunlight in each season (the sliders were dynamically linked with a simulation of the Earth's revolution and translation) and move the points in the graph to the corresponding amount of hours for each of the four dates indicated.*
Activity II *Model*	U0: *Identify (and adjust) the appropriate graph (linear, quadratic, or sinusoidal) to describe the amount of hours of sunlight throughout a year.*
Activity III *Application*	P3: *Move the points in the compass to indicate where the sunrise and sunset would be. (Based on current date.)* P15: *Considering it was an equinox, move the corresponding point to indicate how you think the sun path would be in the sky. (The point could be moved to show a path mainly in the southern/northern region of the sky, or a path passing through the zenith.)* P24: *Orient the solar panel so that during an equinox it would take as much energy as possible. (The panel could be oriented to a cardinal direction and its inclination could also be changed to a specific degree.)* P32: *If we want it to work better these days, what should we do? (Increase its angle or decrease it, based on current date.)*

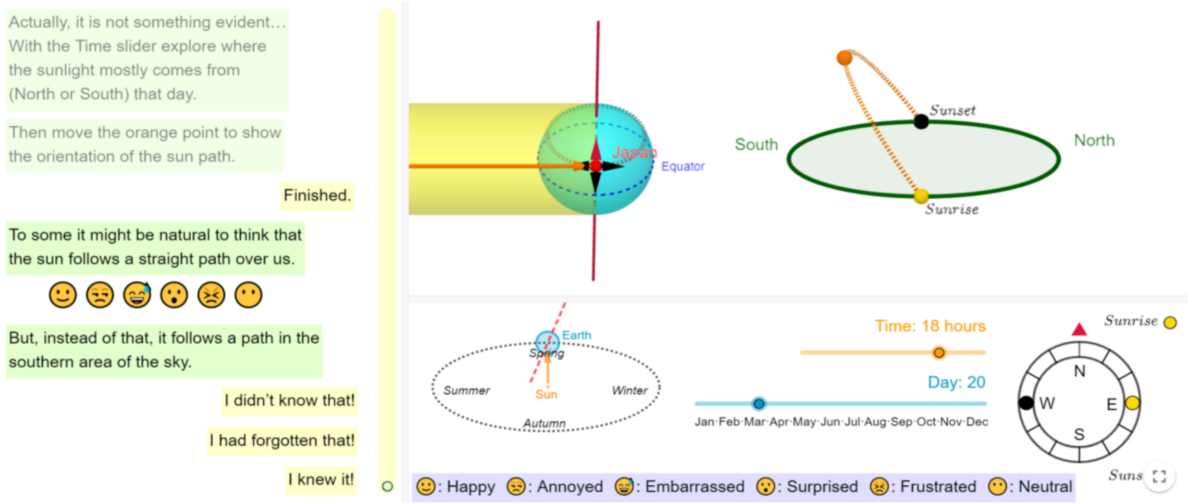

Figure 1. Applet Layout (Activity III – *Application*)

In the dialogue area, the student is guided through directions and questions related to the graphic area. On each task, the system waits for an action from the student and, whether it is an answer selection or an adjustment in the graphic area, it evaluates the action providing the corresponding feedback. In this way, the system addresses the need for monitoring, and allows a self-adapted pace as students can follow specific solving paths. As for the need to express a position towards the feedback received, there are moments when the student can select one of three answer options (in blue in Figure 2) and obtain the same reaction from the system regardless of the selection.

Type and Purpose of Feedback

Since the *affective value* of the environment in this experiment is explored based on the affective response to the feedback provided by the system, special focus is given to how the feedback was constructed (*type*) and when it was delivered (*purpose*). Regarding *how* it was constructed, two types of feedback were devised considering the research results and theories presented in the subsection *Feedback and Emotions*. Type I (*task-focus/constructivist*) was based mainly on Feedback Intervention Theory, while Type II (*self-focus/motivational*) on Attribution Theory. An example of both types can be seen in Figure 2. The coding "P#" and "G#" corresponds to directions, questions, and feedback (feedback with two types is shown in bold on each shaded area). The "R#" corresponds to the answers the student can select.

As for *when* feedback was delivered, depending on the action of the student, the purpose of the feedback would be either *correction*, *completion*, or *suggestion*. The emojis shown in the shaded areas in Figure 2 indicate the moments when the student could select a *reaction* (happy, annoyed, embarrassed, surprised, frustrated, or neutral) to the feedback provided. In each case, more than one reaction could be selected, and students could select and unselect the reaction at any moment during the activity (they could go back by using the scrollbar).

The options for the reactions were selected based on the epistemic emotions *enjoyment*, *surprise*, and *frustration* considered by Chevrier et al. (2019); and the activity and retrospective emotions *anger* and *shame* considered by Muñoz et al. (2016). The option of *neutral* was added to verify that the student did not forget to select a reaction, and a reminder was also included at the end of each applet to prevent this omission.

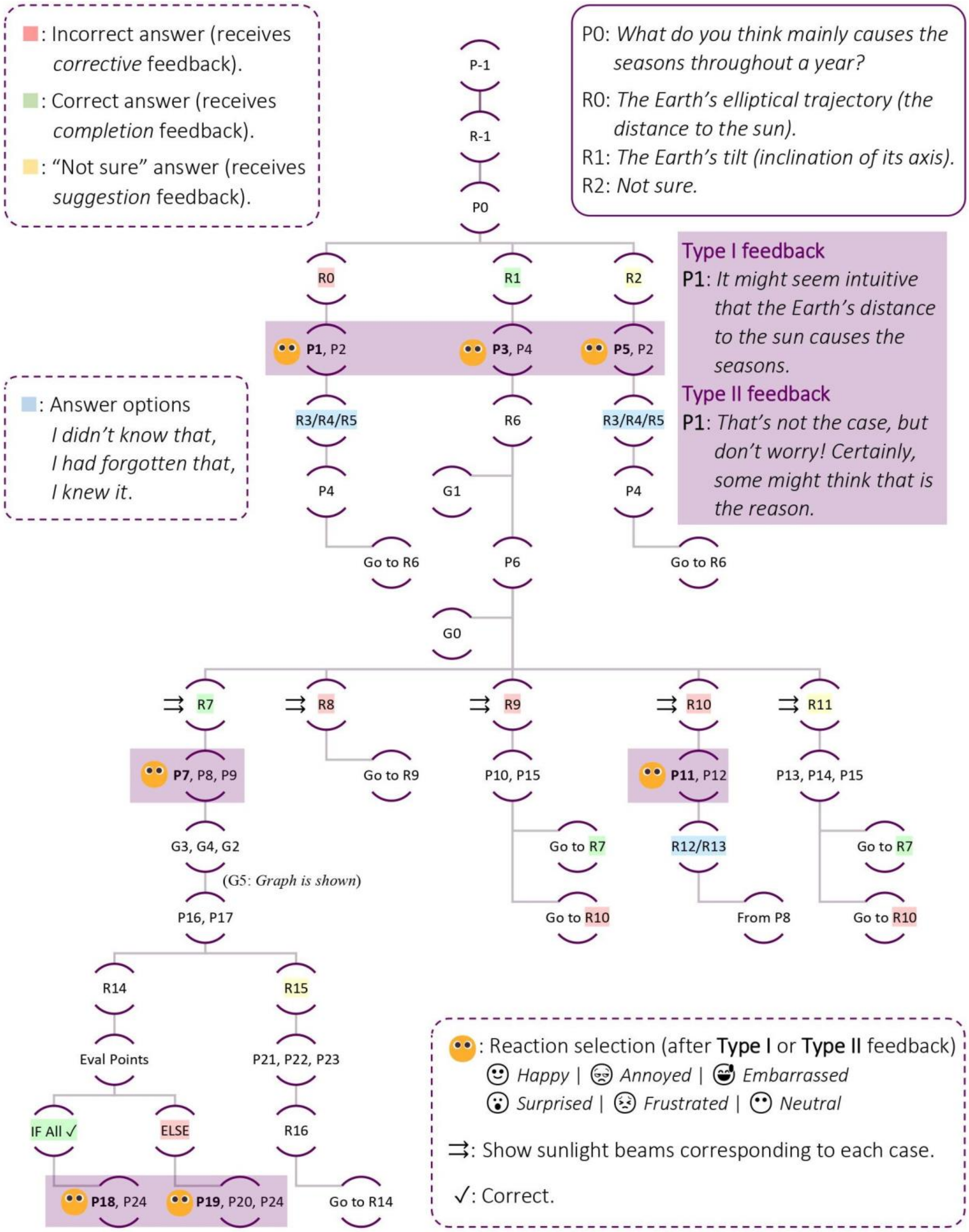

Figure 2. Diagram of Interactions for Activity I

General Perspective of Feedback

To explore what students thought about the activities and the feedback they received, two questions were included at the end of the experiment:

(1) *How did you feel while solving the activities?*

(2) *What do you think about the guidance messages you received?*

On the other hand, to have some indicators from the students about the attributional sensitivity and perceived utility of feedback in general, eight statements (see Table 2) based on the *Instructional Feedback Orientation Scale* (King et al., 2009) were included.

Table 2. Statements and Likert Scale Options for Each Statement

Statements	Likert scale (value)
1. The possibility of receiving positive feedback is very encouraging.	Strongly agree (2) Agree (1) Neither agree nor disagree (0) Disagree (-1) Strongly disagree (-2)
2. I usually am able to improve my performance based on feedback.	
3. I pay careful attention to instructional feedback.	
4. Corrective feedback is embarrassing and/or intimidating.	
5. I feel relieved when I receive positive feedback.	
6. It is difficult to "get over" corrective feedback.	
7. I don't need positive feedback when learning.	
8. Corrective feedback is helpful.	

Source: 1 to 6 from the *Instructional Feedback Orientation Scale* (King et al., 2009), 7 and 8 added by the authors. Note: 7 was reverse coded for the analysis.

Implementation

To share the activities with the participants, two *GeoGebra Books* were created and uploaded to the platform; each *Book* contained the three activities with one of the two types of feedback (*self-focus/constructivist* or *task-focus/motivational*). Besides the activities, the *Books* also included an Introduction with an applet that explained the interaction process for solving the activities, and a Conclusion with the questions and statements relative to the activities and feedback in general, as well as some demographic questions. The students that agreed to participate in the experiment (thirteen engineering students at a Japanese university, two females and 11 males, aged between 20 and 23 years) were given a link to access at any moment they considered convenient and, when doing so, they were randomly assigned to one of the *Books*.

Data Gathering

The activities were designed so that the *actions* of the students in the applets were saved in the platform with their corresponding time stamps and, when applicable, a specific value (e.g., a degree of rotation). An *action* consisted of selecting an answer, adjusting something in the interactive graphic area, or selecting/unselecting an emoji to react to the feedback provided. Through this data, the solving path followed by each student could be identified, as well as the time they spent between each pair of actions. In the case of the Introduction, the students' interactions with the sample applet were saved in the platform. As for the Conclusion part, the answers to the open-ended questions and the Likert scale selections were also saved.

Results

Activities

Regarding Activity I, an example of an incorrect adjustment for P16 is shown in Figure 3. In this case, the student would receive the corresponding *corrective* feedback and be shown the correct adjustment (orange circles in the graph). As for Activity II, the system identified and registered the incorrect graph adjustments of the sinusoidal based on its period and amplitude. Figure 4 shows the common errors (in purple) and the correct adjustment shown by the system (in orange) after evaluating and providing the corresponding feedback.

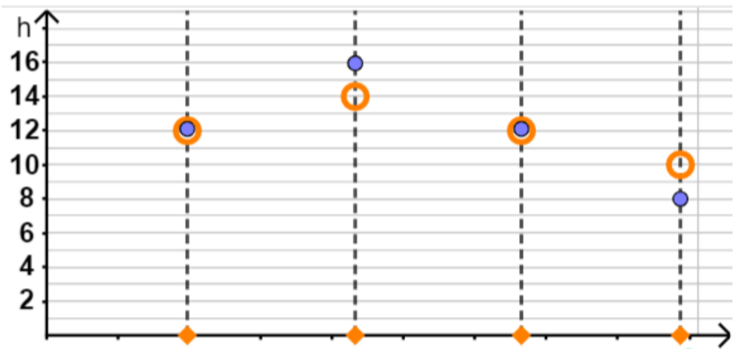

Figure 3. Example of Incorrect Adjustment

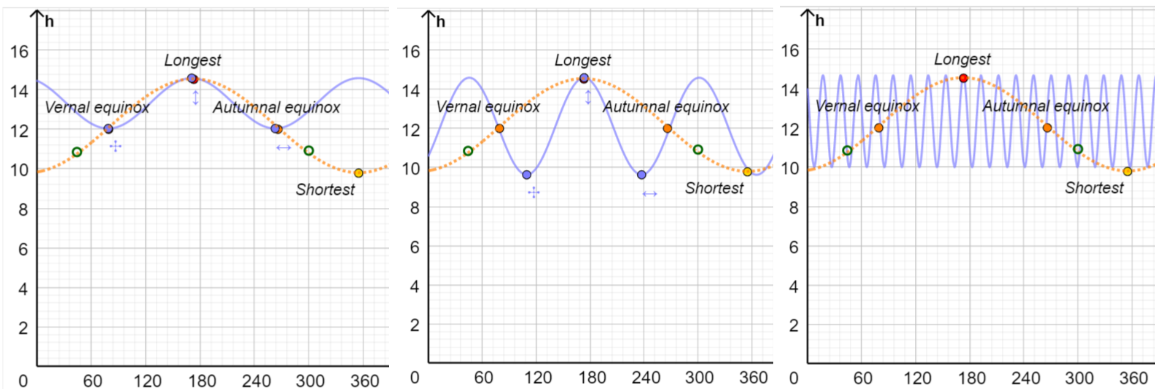

Figure 4. Common Errors when Adjusting the Sinusoidal

In the case of Activity III, the most frequent misconceptions for P3 are shown in Figure 5 (first two compasses), as well as the correct adjustment for the specific date (last compass), which only one student answered correctly. Overall, except for elements P6 and P16 of Activity I (Table 1), the frequency of incorrect answers was higher than that of correct and "Not sure" answers in all activities. The frequency of each answer for the elements described in Table 1 is shown in Table 3.

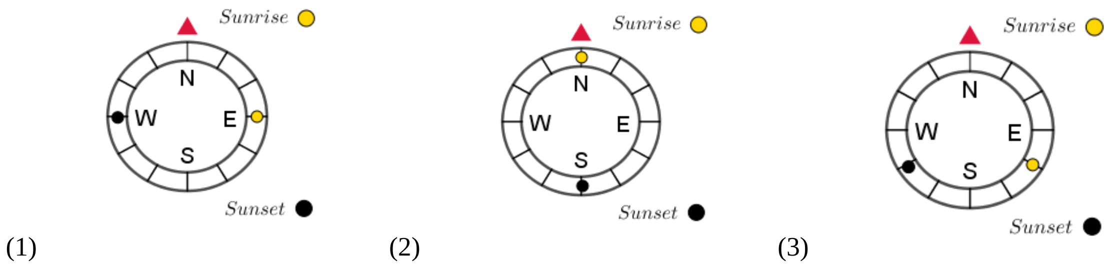

Figure 5. Common Misconceptions (1 and 2) and Correct Answer (3)

Table 3. Frequency of Incorrect, Correct and "Not Sure" Answers

	Activity I			Activity II	Activity III			
	P0	**P6**	**P16**	**U0**	**P3**	**P15**	**P24**	**P32**
Incorrect	6	0	5	5	9	8	10	5
Correct	5	9	2	4	1	3	0	5
Not sure	2	4	6	3	3	2	3	2

Note: One student (TM3) skipped Activity II and another student (TM6) skipped P32.

Type and Purpose of Feedback

To model the reaction selection per feedback purpose, the graphs shown in Figures 6 and 7 were created. The values in the vertical axis (*reaction selection*) correspond to *happy* (2), *surprised* (1), *neutral* (0), *embarrassed* (-1), and *frustrated* (-2, Figure 6) or *annoyed* (-2, Figure 7). The horizontal axis corresponds to elements of the activities and the initials *DK*, *HF*, and *KI* stand for *I didn't know that*, *I had forgotten that*, and *I knew it*, respectively. The values in the upper right corner of each graph correspond to the scale presented in Table 2; a higher value corresponds to a greater sensitivity to and perceived utility of feedback in general.

In Figures 6 and 7, the color of each point indicates the *purpose* of the feedback (red: *correction*, green: *completion*, yellow: *suggestion*). In the title of each graph, the F stands for females and M for males, while the dotted line shows a selection that was unselected after 10 seconds or more.

An overview of the reactions selected by the students who received Type I feedback (*task-focus/constructivist*) and Type II feedback (*self-focus/motivational*) depending on the *purpose* of the feedback is presented in Table 4. *Annoyed* was selected by three students (two in Type I group and one in Type II group) after *correction* (two in U0 of Activity II and one in P3 of Activity III), but they unselected it immediately or at the end of the activity (see SM4 in Figure 7).

Considering the 127 moments when students received feedback (75 in Type I group and 52 in Type II group), the distribution of the *purpose* of the feedback is shown in Figure 8. Regarding the answer options, from the 27 selections in Type I group, 16 selected *I knew it* (KI), 9 selected *I didn't know that* (DK), and 2 selected *I had forgotten that* (HF); from the 20 selections in Type II group, 10 selected DK, 6 selected KI, and 4 selected HF (the moments of these selections are indicated in Figures 6 and 7).

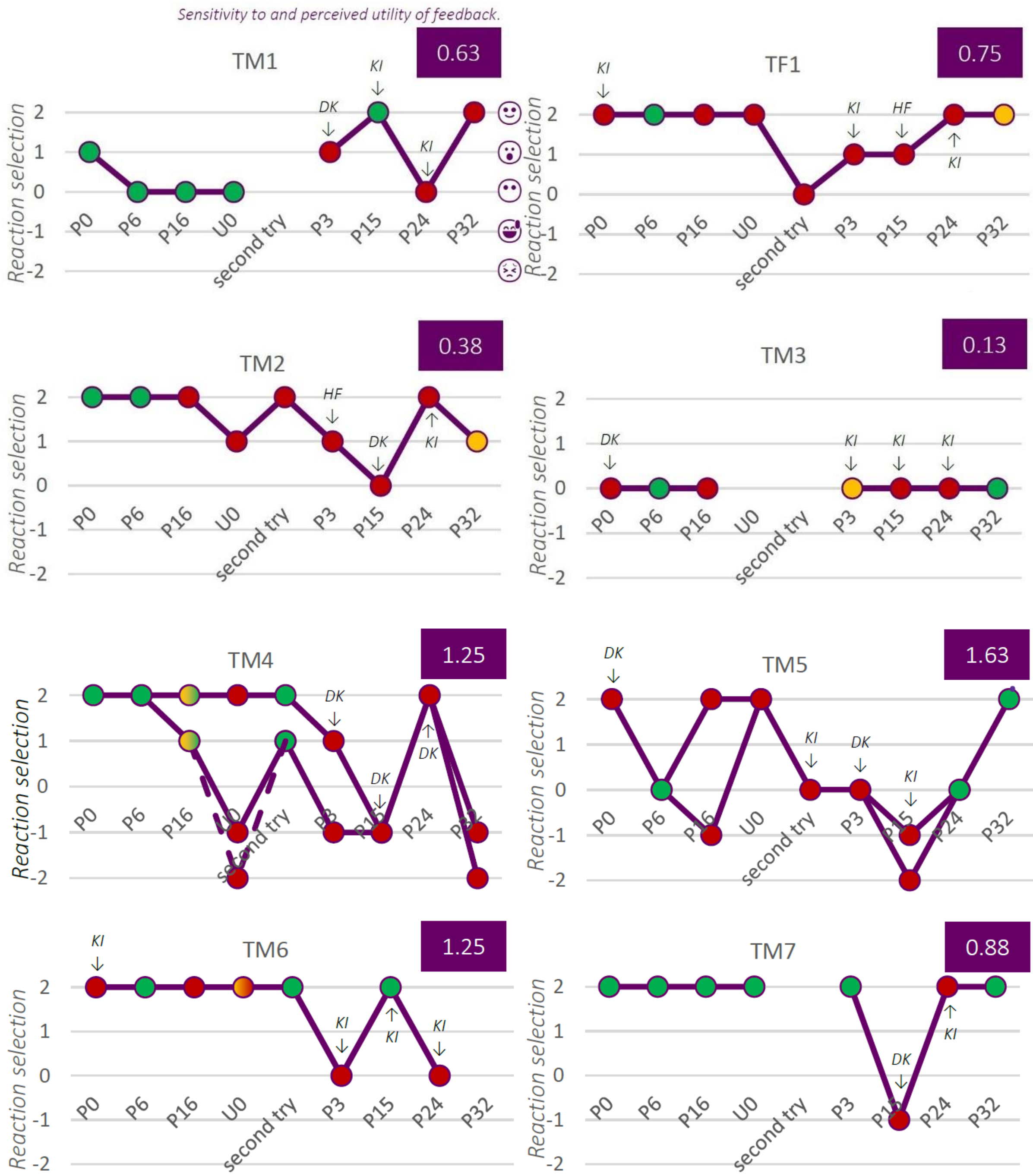

Figure 6. Reaction Selection per Feedback Purpose (Type I group)

Table 4. Reaction Selection per *Type* and *Purpose* of Feedback

Type of feedback	**Percentage of selection (*purpose*: correction / completion / suggestion)**					
	Happy	***Neutral***	***Surprised***	***Embarrassed***	***Frustrated***	***Annoyed***
Task-focus/ constructivist	.48 (.23/.24/.01)	.25 (.15/.09/.01)	.13 (.08/.04/.01)	.09 (.09/.00/.00)	.04 (.04/.00/.00)	
Self-focus/ motivational	.42 (.19/.19/.04)	.21 (.15/.02/.04)	.21 (.13/.06/.02)	.14 (.10/.00/.04)		.02 (.02/00/.00)

Note: In total, 75 reactions were selected in Type I group and 52 in Type II group.

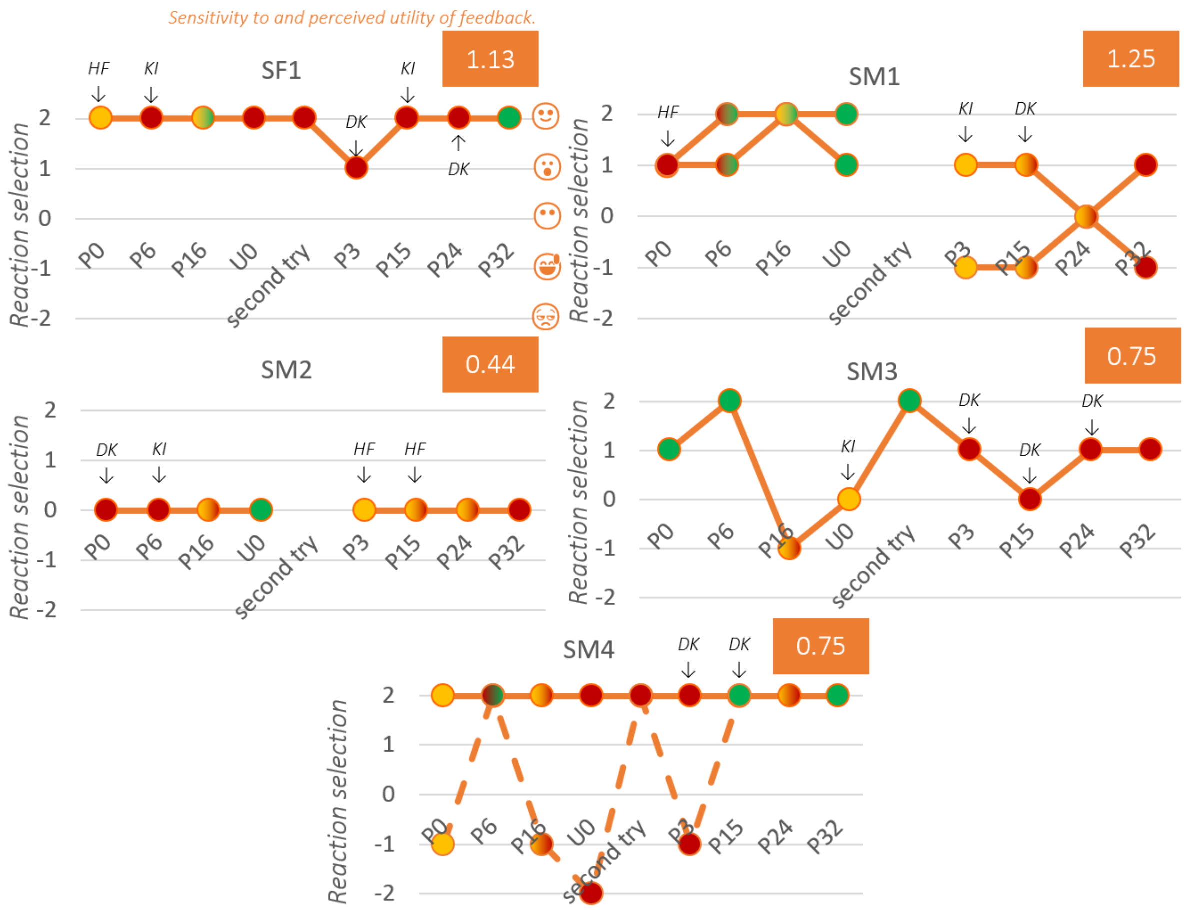

Figure 7. Reaction Selection per Feedback Purpose (Type II group)

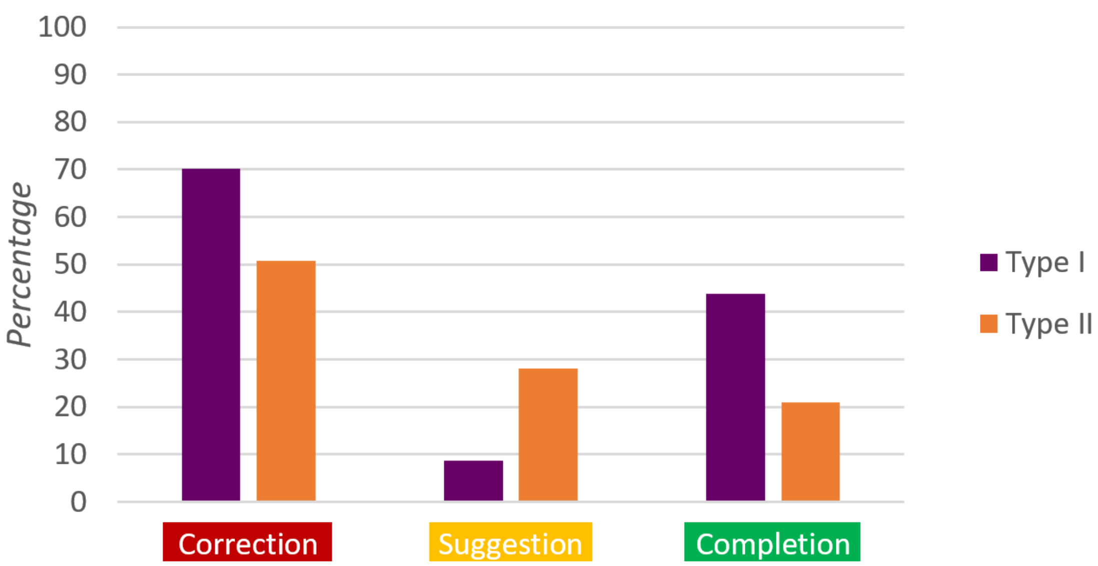

Figure 8. Percentage of Feedback Purpose per Type of Feedback

General Perspective of Feedback

The average values given to feedback based on the statements in Table 2 are shown in Figure 9 for each type of feedback. As for the two questions about the experience, it was noted that participants who received Type I feedback (*task-focus/constructivist*), used in their answers more words related to the task, such as *confused/confusing*, *educating*, *refreshing*, *intrigued*, *curious*, *interesting*, *helpful*, *clear*, and *informative*; while students who received Type II feedback (*self-focus/motivational*) used more words related to emotions, such as *enjoyed*, *interested*, *motivated/motivating* and *comfortable*. Two answers shared by the students are: “I think it's good science guidance. Even when participants made the wrong choice, the message did not contain a critical tone, which somehow encouraged them to continue learning” (TF1) and “I felt intelligent and stupid at the same time, but nevertheless, I enjoyed it” (SM1).

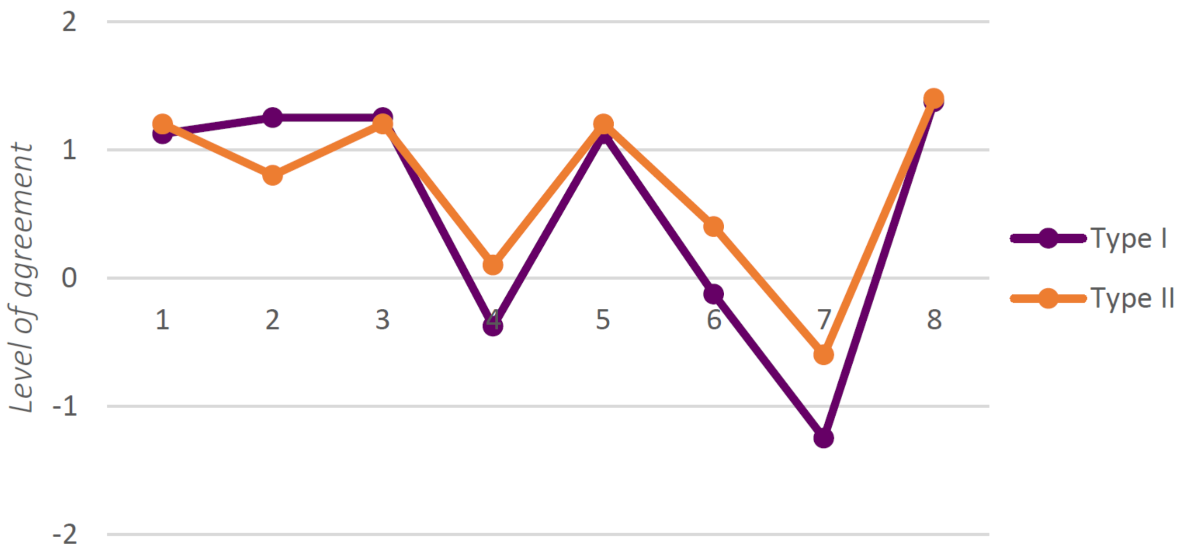

Figure 9. Levels of Agreement to Statements in Table 2

Discussion

The last two comments reflect a main motivation for this research, to create a digital learning environment with attention to its *affective value* through feedback design. It is noteworthy that although solving the activities would not be reflected on the grades of the participants, most of them selected varying emotions when feedback was provided, supporting the idea that feedback is an inherently emotional issue (Molloy et al., 2012).

This idea was also supported by the values obtained from the students’ levels of agreement with the statements based on the *Instructional Feedback Orientation Scale* (King et al., 2009), as they generally agreed on the relevance of receiving positive feedback (Figure 9); moreover, these values provided an insight into students’ perceived utility of and sensibility to feedback, which was reflected on the models constructed for each participant in both groups (Figures 6 and 7). Students with the lowest values in each group were the ones who always selected a *neutral* reaction, while those with a higher value tended to select a reaction related to the *purpose* of the feedback received. Roughly speaking, these students selected a positive/negative reaction after receiving corresponding positive/negative feedback; however, other behaviors were also observed.

In particular, the percentages of selection of *happy* and *surprised* were slightly higher in the Type I (*task-*

focus/constructivist) group compared with the other emotions, while *surprised* and *embarrased* were slightly more frequent in Type II (*self-focus/motivational*) group; the least frequently selected, *frustrated* and *annoyed*, only appeared, respectively, in Type I and Type II groups (see Table 4). Although more data would improve a quantitative analysis of these differences, the models constructed allow a qualitative analysis to explore the emotional impact of specific feedback. For example, TM1 (Figure 6) expressed that he thought that the reaction buttons were unnecesary until the middle part of the activites, when he received his first *corrective* feedback; this suggests that the use of reactions can emerge as a necessity to express.

Furthermore, the models can inform future designs based on the potential of feedback to promote positive reactions. As an example, four students in Type I group reacted positively to the *corrective* feedback provided in P24 after having just received another *corrective* feedback, and even after having reacted with embarrassment (TM4 and TM7) to it. The four students received similar feedback emphasizing their specific achievement: "You've accomplished a relevant part of the process, which is *concluding that the panel should face the south!/exploring different orientations!*"; therefore, if a topic is expected to be challenging, feedback could be expressed in this terms.

Nevertheless, the latter may also depend on the type of feedback, as SM1 received a similar feedback in P15: "Your assumption of the sun not following a path right over us is an important realization!", yet still selected *embarrassed*. The same occurred with SM3 in P15, so this might be because in Type II feedback focus was placed on the *self*, in contrast with the previous examples where focus was placed on the *task*.

On the other hand, students who received Type II feedback were more likely to ask for suggestion compared to those in Type I group (see Figure 8), and depending on the learning goals this might be desirable. Furthermore, students in this group were more likely to select *I didn't know that*, in contrast to students in Type I group who tended to select *I knew it* more frequently. This may be related to the face threat mitigation tactiques considered in Type I feedback and may also suggest that Type II feedback makes students feel more open to admit lack of knowledge. Moreover, the difference observed in word use (task-related in Type I group and emotion-related in Type II group) suggests an influence of feedback design in how students reflect on their experiences while solving the activities.

Conclusions

These results show the viability of exploring the *affective value* of educational technology based on its feedback design, particularly seeking to promote stable emotional environments when learning challenging STEM topics using *dynamic reasoning*. Regarding the guidance, in general, students agreed on its utility and clarity, some of them even alluding to its *comfort*; this is consistent with the exploration of Grossman et al. (2019), who confirmed the possibility of creating conversational experiences without needing to support true dialogues that ask and answer open-ended questions. Besides, in line with the same research, it is highlighted the strength of these type of environments in that teachers might be able to participate in its development, especially when they are constructed on a common educational software such as GeoGebra. As for the limitations of the study, a bigger sample would give a better perspective on the differences in effects of both types of feedback, while a more extensive qualitative analysis could provide more specific hints into how same types of feedback provided in similar moments may have different effects depending on the student.

In conclusion, it is argued that feedback has unavoidably an affective component, even when designed with a focus on the task. This becomes critical when considering the increasing use of conversational technologies that goes beyond abstract transactions, creating on users the expectation of receiving feedback with emotive content. At the same time, this type of interventions may alleviate the pressure on teachers to provide *corrective* feedback, as it has been shown that acting as the source of external feedback can be as equally stressful as assuming the recipient position (Molloy et al., 2012). Finally, for future work, it is recommended to extend the *affective value* definition regarding educational technology, considering the aesthetics or other affective elements in its design.

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