# Illuminated feedback in an online classroom: Will it help or hinder?

Nikki Zandbergen
University of Twente
P.O. Box 217, 7500AE Enschede
The Netherlands
n.zandbergen@student.utwente.nl

## ABSTRACT

Due to the many uncertainties that the current COVID-19 outbreak carries, there are worries about the mental health of many students. This research shows whether biofeedback can help students in these times, by delivering illuminated feedback during online classes. This paper analyses existing literature on the area of illuminated biofeedback online, and adds to existing research by presenting the results of an online questionnaire as well as results of an exploratory user study. From the literature research it can be concluded that there is potential in the technique of illuminated biofeedback to support students by soothing stressed users and increasing group coherence. The user study showed an increased sense of coherence while using the technology. However, from the questionnaire and user study, several subjects indicated to feel exposed when sharing their emotional state individually and preferred feedback on group level. In conclusion, illuminated biofeedback carries potential to connect students by adding new forms of expression during online classes. Additional research should verify what this technology can bring in online classrooms.

## Keywords

Illuminated feedback, Biofeedback, Students, Online, Design research, Group coherence

## 1. INTRODUCTION

During the current COVID-19 outbreak, around 890 million students in 114 countries are forced to study from home in online classes [3]. Because of the many uncertainties that this outbreak carries, such as economical consequences, doubts of the future, or health issues, many universities fear that this will affect the mental health of their students, also while recovering from the impact after the crisis [3].

In order to help these students - and possibly many others who are struggling with homebound work - a technique that is proven effective could be used, namely biofeedback. The idea of biofeedback is to enhance people with the information from their body, such as respiratory rate, heart rate and temperature, so they can use this information to (consciously) manipulate their body and mind. This technique has already proven to cure or ease diseases as ADHD [27], migraine [36], and anxiety [7, 43].

This biofeedback can be displayed to the user in different ways, such as with audio, physical, and visual means. To make biofeedback possible in a group setting over an online video connection, visual feedback is chosen. For this research the focus will be narrowed to illuminated feedback. With illuminated feedback, the biofeedback is received in a form of light. This light can vary in brightness, colour and frequency of flicker to communicate with the user [12]. Different wearables are already being designed to be able to show the internal emotions on the outside with the help of visual means, such as the SWARM scarf [52], Breeze pendant [12], TOBE robot [13], Hint t-shirt [19] and GER Mood Sweater [47].

In these cases, biosensors are often used to translate different signals of the body to display the actual emotional state someone is in. This form of feedback is something Sensoree [48] describes as extimacy - external intimacy. Extimacy is showing how you feel on the inside, to the outside world [35].

Extimacy in biofeedback can help achieve group coherence. Group coherence, or social coherence, occurs when multiple people in a physical group are engaged. Social coherence can improve the way we feel, communicate, and behave, thus improving our psychological state [28].

This research will focus on applying illuminated biofeedback in an online classroom setting. The following research question will be answered:

*How can illuminated biofeedback help or hinder in an online classroom setting of high school and university students?*

Figure 1 shows how such an illuminated biofeedback sys-

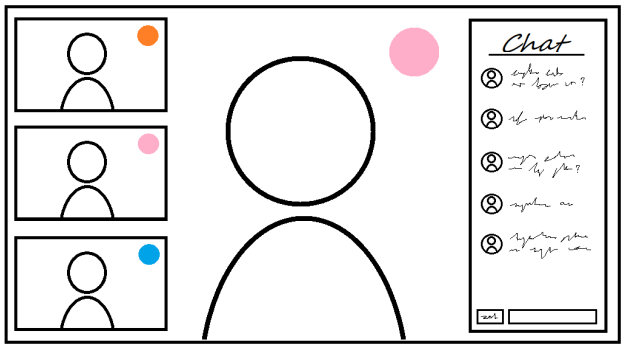


**Figure 1. Example of the illuminated biofeedback technology in an online classroom**


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tem could look like. In this case, the emotional state of the student can be measured via facial expression recognition software, and this emotional state can then be displayed with a coloured dot next to that student.

This research consists of three parts. Section 2 examines existing knowledge on the fields of social coherence, illuminated feedback, biofeedback for students, and biofeedback online, by literature research. Section 3 shows what students think of the COVID-19 situation and the application of biofeedback, through an online questionnaire. Section 4 consists of an exploratory user study, where the applicability of biofeedback in a non-physical environment is tested.

This research will be the the first to explore the applicability of biofeedback in online classes. By collecting opinions of students and running an exploratory user study, the research will shed light on the possibilities of the technology, and its shortcomings. The paper will analyse how this technique could help the students, or hinder them, by exploring what is already known about the effects of the technique, and seeing how subjects react to it. The insights of this paper can be used for further research in this area.

# 2. RELATED WORK

## 2.1 Social Coherence

A lot has already been researched about the effects of social coherence and how to reach this through biofeedback means. The main technique used to detect social coherence is heart rate variability (HRV). HeartMath [15] develops several HRV-based biofeedback technologies and researches the field extensively. The possibility of heart coherence through HRV has already been proven [10, 26, 28, 33] and achieving social coherence through these HRV techniques is shown to improve aspects like test anxiety [7], work spirit [10], stress levels [25, 43], self-regulation [27, 45], cognitive performance [41, 54], and proficiency in math and reading [29].

This research in HRV biofeedback leaves room to assume that biofeedback delivered from other measures of the body to visual means can also deliver these benefits. Although research on other biofeedback-based systems has not been as extensive, there is evidence to support this assumption: a group of 22 yoga students experienced higher croup coherency with visual biofeedback [32]; it is proven that illuminated feedback can increase self-awareness [44, 49]; different colour schemes are able to influence behaviour (colour psychology) [4]; and visual biofeedback strategies combined with video games have shown to promote positive emotions and team work [34]. Naturally, all of the mentioned benefits reachable through HRV or visual biofeedback can be useful for students when it comes to online classes.

Several studies have been conducted with high school and university students, of which some of the studies that were already mentioned [7, 10, 29, 45]. Additionally, the effects of biofeedback-assisted relaxation therapy for university graduate students has been researched, where the greatest improvement was seen in the decrease of physical aches [8].

The discussion above shows that creating coherence in a group is possible with the help of biofeedback techniques and can bring many benefits. However, there are some side notes to be made for the applicability of the mentioned works for this research. Many of these results were only achieved through extensive training [7, 8, 25, 29, 54]. Also the subjects for these researches were often not in the age range of high school and university students [10, 25, 27, 41, 54]. From this, it could be that the effectiveness differs for high school and university students that do not receive extensive training.

## 2.2 Biofeedback on Students

For the area of this research, it is important to know whether biofeedback impacts people in the age range of students differently.

Fortunately, students and adolescents were often part of the subject group of biofeedback related researches. Often, these researches were focused on reducing stress [8, 41], creating emotional stability [7, 9, 34] and improving cognitive skills [7, 29].

These same researches have shown to improve mindfulness [7, 8, 29], cognitive performance [29, 41], confidence [8], collaboration [34], and general positive emotions [7, 29, 34]. They also showed biofeedback can help to ease physical pains [8], and reduce anxiety [7, 9, 29, 41]. One research even showed that collective training with HRV-biofeedback was able to result in the heart coherence of a class of high school students [7].

However, research on students is not limited to the attempt of reducing the negative aspects of the busy student life. Illuminated biofeedback on students has shown to reduce the time in which a new skill can be learned [6], and dance students trained with biofeedback showed improved timing and technique [42]. Furthermore, biofeedback can improve the cognitive performance of adolescents with autism [24], and can even reduce the feeling of guilt while snacking [31].

These studies indicate that biofeedback is indeed also effective for people in the age range of adolescents and students. However, they do not show whether there are differences in the amount of training required, or the overall effectiveness with respect to other age groups.

One study showed an age comparison on the effectiveness of biofeedback training for reducing headaches [46]. The results show that the improvement in children after the training were twice as high as in adults. Also the increase after the treatment was higher in children. However, the author of [46] did leave some comments on these findings. The effects could be explained by the fact that children are more enthusiastic and less sceptic about the technology, and that they stuck better to their training than adults.

This shows that biofeedback can be an effective treatment for adolescents and students. From the researches it could not be shown that adolescents and students require less training or a different approach than adults.

## 2.3 Illuminated Feedback

It is also interesting to investigate whether the way in which biofeedback is offered can cause different effects on the person receiving it.

A small study shows the first reaction of people to different kinds of biofeedback [52]. In this study, participants indicated that vibrations were useful to alert the user for sudden changes in emotion. Also the use of warmth to sooth stressed users was considered useful by the participants. Another small study compared audio, visual, and haptic means of delivering the biofeedback [12]. Most participants were positive about sound feedback, since it was easy to understand and mimic. The visual feedback was considered helpful when wanting to understand the feelings of others. Feedback in the form of vibration often led to more stress, relating it to phone notifications.

In this study, the focus is narrowed to the use of illuminated feedback. When comparing illuminated biofeedback to other means of displaying biofeedback (e.g. vibration, heat, dashboard app) it is unique in the sense that it does not only deliver the feedback to the user itself, but also to everyone surrounding this user. This makes illuminated feedback suitable for means of extimacy.

This extimacy, however, is not always appreciated by the user. Throughout different studies regarding illuminated biofeedback, privacy is a recurring topic. Often, studies had at least one participant mentioning extimacy as privacy concern [12, 52]. Some participants showed to be against sharing their emotional state [12, 44, 52], while others felt too ashamed to share their emotional state, fearing it would give others the wrong impression [19, 44]. From these studies, around 30% of the participants had issues regarding this topic.

Nonetheless, most of the participants of these studies mentioned sharing their emotional state through illuminated feedback was something beneficial [12, 13, 44, 52]. Some participants mentioned that they would like the concept only if it is limited to displaying positive emotions [44, 52]. It also makes it easier to imitate emotions [12] and provide support [13, 44].

The aforementioned results show that, although there is some criticism regarding the publicity of the feedback, most participants appreciated the shared feedback and experienced positive effects.

Still, research on illuminated biofeedback on its own is rather limited. However, from the basic principles of illuminated feedback (colour, intensity, frequency of flicker) there is enough evidence that proves the potential of this technique.

Research on colour psychology shows that people react emotionally and cognitively to visual imagery, called affective visualization [4]. This affect is largely influenced by the colours. Colour can carry information and can influence people's affect, cognition and behaviour [11]. People also have similar ideas of how a specific affect can be represented by colours [4]. This implies that a group of people, exposed to a coloured light, will have similar emotions associated to that light.

Light has also proven to be an effective mean for easing various diseases. Light exposure therapy can be used to ease different kinds of depressions, such as seasonal depression [5, 14, 38], bipolar depression [38] and chronic depression [14, 38], but it can also help for something as simple as improving mood [1, 2] and social interaction [2].

The benefits from these basic characteristics of light are appealing when wanting to help individuals who are coping with feelings of loneliness and stress. Illumination could be the way to suppress these feelings in a way which becomes almost unnoticeable.

Various ambient light systems are already being developed for this purpose. Examples are DeLight [55] and MoodLight [49]. DeLight is a biofeedback lighting environment that operates purely on lights. It measures the heart rate variability of the user and adapts the colour of the lighting system accordingly. DeLight illuminates the room, covering it in a sea of colour. It is proven effective for relaxation, stress reduction, and increased self-awareness [55]. MoodLight is a system with similar characteristics, but measures electrodermal activity for adapting the colour of the lights. MoodLight has shown to improve self-awareness [49].

Other examples of biofeedback devices that operate purely on illumination are BioCrystal [44] and GER Mood Sweater [47]. BioCrystal is a small ambient biofeedback device that measures the affective state of the user and communicates it via a small ambient display. BioCrystal is designed as a mood sharing device and is proven to improve mindfulness and interpersonal communication [44]. The GER Mood Sweater is a wearable that measures users' galvanic skin response to display their excitement level. Research on the effects of this wearable is still ongoing.

The discussion above shows that illuminated biofeedback carries potential. The fact that colours and light have proven to be effective for easing diseases like depression makes it worthwhile to see what more is possible with the help of illumination. Although the technique of illuminated biofeedback has not been researched to a great extent yet, the results of the conducted researches look promising. Most participants liked the idea of illuminated feedback, provided that it displays positive emotions. However, privacy issues are a concern and should be taken seriously in the design.

## 2.4 Biofeedback Online

When wanting to help students during their online classes, it is important to know whether the benefits which can be realized with biofeedback can still be achieved over an online connection.

As mentioned, there has been extensive research on the existence of heart coherence and on how to achieve this. However, these researches were mainly done in a physical setting. Only little is known about the effects when participants meet in a non-physical environment, such as during an online class.

Various biofeedback researches have explored the possibility of providing the feedback via digital means. Examples of such applications are AffectAura [30], Pause [39], Inner Balance [17] and emWave [16]. Each of these applications have proven their success. AffectAura is a memory system that logs the affect throughout the day. It helped the users to reflect, and improved their memory [30]. Pause is designed to increase happiness and showed to be effective [37]. Inner Balance and emWave are both products of HeartMath [15] and proven to increase heart coherence [10, 28, 33], and reduce anxiety [18] and stress [25]. This shows that biofeedback offered via digital means is not by definition less effective.

Furthermore, research on communication also supports the idea of enhancing conversations through online means. For example, the area of social robots proves that communicating *with* digital means is already possible. Additionally, there has been research on how to make digital agents recognize emotions via camera and audio [40], thus allowing biofeedback to be delivered without the need of attaching the user to various sensing devices. Research also shows that the most important factors for an engaged conversation are attentiveness and enthusiasm [21]. Thus, when a biofeedback system can enhance these aspects, the connection of people online can be improved.

The BBC wrote an article about why online meetings drain mental energy [23]: it becomes more difficult to see nonverbal cues; the small delay makes it feel unnatural; and the fact that you cannot look each other in the eyes also requires more mental effort. Furthermore, being able to see your own face makes many self-aware, naturally drawing their attention to their own appearance [23].

This shows that meeting in a non-physical setting requires more effort than meeting in person. Therefore, being able

to create more connection during an online meeting is essential.

A few studies have researched the possibility of enhancing people via an online connection. [22] researched the effects of additional information on the self-reported affect of participants during video viewing. It showed that a combination of heart rate biofeedback and chat functionality improved the affect. Biofeedback alone did not result in a significant change. [50] revealed that visual stress indicators improved collaboration and reduced stress. [34] showed that biofeedback driven video games enhanced positive emotions, collaboration and team work.

Thus even over an online connection or via digital means, it is possible to achieve the positive effects of biofeedback. No research on the effectiveness of biofeedback technology was found that compared digital and physical means. However, there is enough evidence that supports the idea of being able to connect people over a non-physical online connection.

# 3. STUDENT SURVEY

## 3.1 Study Goal

The online survey was used to find answers to two different questions. The first aims to discover what students think of homebound schooling, how this affects them, and whether they like or dislike homebound schooling more than physical (traditional) education. The second question aims to discover what students think of illuminated feedback during online classes. The pure hypothetical case description explained students what illuminated feedback during their online classes could look like, and asked them their opinion on this.

## 3.2 Method and Approach

For this research, a questionnaire has been distributed amongst students across the globe. The questionnaire consisted mostly of multiple choice questions, but some open questions were included as well to collect extra insights.

The survey has been distributed by online means and contained a total of 51 questions. Of these, 23 questions were dedicated to get insights into the experiences of students, and 21 were dedicated to illuminated feedback. A total of 64 students responded to this survey. Two responses were removed, since they indicated 'not applicable' for every closed question. A written consent has been provided to the participants before the start of the survey. This study has been approved by the Ethics Committee of the University of Twente [51].

## 3.3 Results

The participants of this survey were aged between 17 and 35, with a mean of 23. The gender of the participants was evenly spread. All respondents studied in the Netherlands. Of the respondents, two were high school students, nine were University of Applied Sciences students, and the other respondents were University students. Of the University students, 34% was international, with nationalities from Belgium, Germany, French, Greece, Hungary, India, Lithuania, and Poland. Around 10% already had experience with homebound education.

When asked about their personal experiences regarding homebound schooling, 50% indicated they prefer physical education over homebound schooling, and 55% wanted to return to physical education, while 28% preferred homebound education, and 19% wanted to retain it.

Regarding the first research goal for this survey, the students responded well on the questions asked. In general, students indicated they had more time off during homebound schooling (64%), and more time available to work on gaining new skills (60%). However, there is a split between students who can arrange their work better during homebound schooling, and who cannot. Also, the majority of the students indicate that they cannot work as efficiently from home (60%). When asked their opinion on the benefits of homebound schooling, students mostly indicated that it saves travel overhead, they experience more time off, and are more flexible on scheduling their daily activities. When asked their opinion on what they do not like, they mostly indicated the lack of social contact, various technical defects, online proctoring, contact issues, lack of concentration, lack of a dedicated working environment, lack of structure, loss of practical education, and that they generally need more self-discipline to get to work.

Regarding the feelings that students experienced during homebound schooling, most participants indicated they felt more lonely (66%), less energetic (61%), exercised less (50%), procrastinated more (61%) and had less contact with their friends (69%). On the aspects regarding level of stress, happiness, difficulty of the homework and the situation at home, feelings varied. In general students did not experience additional feelings of depression (84%), or worse quality of sleep (81%). Nevertheless, having 15% of students indicating additional feelings of depression is alarming. That is, since the World Health Organisation (WHO) recently published information stating that a little less than 3,5% of the world population suffers from depression [53]. Although students generally suffer most from depressions, this increase should not be ignored.

Regarding the second research goal of this survey, the students gave clear insights in how their homebound education looks like. Students received up to twenty hours per week of live video lectures (mean 5), including six who did not receive any. Most students indicated they are rarely visible during online lectures (82%), neither are they often requested to speak (76%). The chat functionality is used more often, but generally also not more than half of the time (66%).

When asked on their experiences regarding live video lectures, students indicated that they generally do not feel comfortable being visible during online lectures (71%), or when having to speak (61%). From the students, 60% indicated that they feel more comfortable answering questions of the teacher in a physical setting, while only 13% preferred online. Regarding live lectures, students indicated that they like the chat option. Some indicated that it lowers the threshold to respond or ask questions. They also indicated that students are often only visible when smaller groups are lectured.

Regarding the illuminated feedback technique, students generally indicated that the technique sounds intriguing (55%). Opinions were divided on whether receiving feedback about the own emotional state and that of the peers would be useful, and also about the potential of the system, in terms of creating more coherence and fun. Nevertheless, students are generally positive about the technique and indicated they could get used to it (50%). However, students also indicated that they would be uncomfortable sharing their emotional state with fellow peers or the teacher (61%), and feel the system requires training (68%). Some are also afraid that fellow peers would make fun of their emotional state (39%). When given the option

to get feedback on the emotional state of the whole class, students generally preferred this over individual feedback (56%).

### 3.4 Conclusion

The aim of this questionnaire was twofold. It tried to find answers to how students are coping during homebound schooling, and it introduced the technique of illuminated biofeedback to ask their opinion on this.

Regarding the first research goal, it was shown that students still prefer physical education over homebound education. Although students experienced benefits relating homebound schooling, more disadvantages were brought up. The main issues mentioned, were the lack of social contacts and the need of additional self-discipline.

The emotional condition of most students also deteriorated since the start of homebound schooling: they felt more lonely, less energetic, and procrastinated more. There is no notable increase in feelings of depression or sleep deprivation.

It can thus be stated that there is indeed a need to create more coherence during online classes. Students long to more social connection and illuminated feedback could be the way to provide this.

Regarding the second research goal, it was shown that students are generally not visible during live video lectures. Only when a small group is lectured, students are generally visible. Students received up to twenty hours per week of live lecture, with an average of five. Generally, students are uncomfortable when being visible, or having to speak during such lectures, and feel more comfortable answering questions in a physical lecture than online. The chat option is generally liked, and students indicated it lowered the threshold to answer or ask questions.

When introducing the technique to the students, opinions were divided. Generally students were positive, but it also received some critical notes. It was doubted whether receiving feedback would actually be useful. Although it was indicated they could get used to the system, they would also feel uncomfortable sharing their emotional state. Privacy seemed to be a concern for a number of participants. A system that would deliver group level feedback was preferred by most.

From this, it can be concluded that the technology is not received with open arms. Students are fearful about their privacy and are concerned the technology would do more harm than good. They also seem to be sceptic about the effects which the technology can bring. Nevertheless, most students are positive and would use the technology. Although most students do not have more than four hours of live lectures per week, the technology could still support students during those lectures.

## 4. USER STUDY

### 4.1 Study Goal

In order to verify whether biofeedback can indeed result in group coherency over an online connection, an exploratory user study was set up. From the heart rate data collected during this study, it should show whether a certain type of feedback is able to create more coherence into the group, by synchronizing the heart rates. A survey afterwards was used to see whether the participants felt a higher sense of coherence using the technology. This study was also used as a design research, to find out what users think of the design and how the technology could be improved.


**Figure 2. Colours of the excitement level display © Sensoree**

### 4.2 Participants

In total ten healthy subjects between 21 and 55 years old participated. None of the subjects within a group were related. Of the participants, 3 were female and the others were male. Participants were either Dutch, Canadian or Romanian. No participants were removed from the research, but one had to drop out due to technical issues. The participants were informed on the purpose of this research beforehand and their participation was voluntarily. This study has been approved by the Ethics Committee of the University of Twente. All participants provided informed consent prior to the experiment.

### 4.3 Materials

For this study, an Android application was developed to enable the use of illuminated biofeedback over an online connection. This application is based on the app developed by Jaiswal [20]. It uses the flashlight and camera of the phone to measure the heart rate from the finger.

Depending on the selected activity, the application displays one of the following types of illuminated biofeedback: true biofeedback, group biofeedback, or no biofeedback. With 'true biofeedback' the heart rate of the user is mapped to a colour that displays the current excitement level of the user. The colours used are shown in figure 2, as also used in researches by Sensoree [47]. With 'group biofeedback' the heart rates of the users are combined and the average is used to display the excitement level. Each screen is updated on the excitement level of the group approximately every ten seconds, again using the colour scheme in figure 2. With 'no feedback', the application was merely used as a tool to measure the heart rates. The screen displayed orange throughout the whole session. This type was used for defining the baseline of each group. The colour scheme and associated emotional states as shown in figure 2 was chosen, since the application would then only display neutral emotions. This is done in order to prevent judgements within the group, which could prevent a feeling of coherence.

### 4.4 Method and Approach

In this study, the technique of illuminated biofeedback has been tested on three groups. From this study, heart rate data was collected to check for synchronization. A short group interview and questionnaire at the end of each workshop was used to check for increased experience of coherence due to the illuminated feedback.

The research was conducted online using Skype. Each participant participated from their own home in a room where they would not be disturbed. The participants were asked to install and test the application before the start of the workshop, with the help of a manual. During each session, the participants followed three 15-minute long mindfulness workshops. During each of these workshops, participants used one of the three illuminated biofeedback modes. Each session used them in a different order. The participants were asked to keep their finger on their smartphone camera throughout the entire session. Each round consisted of breathing exercises, movement imitation and emotion simulation. Participants were asked to fill in a short ques-

tionnaire about their emotional state after each block of exercises. During this session, the participants were monitored on their behaviour towards the application.

After the workshop, the participants were asked on their opinion with a short group interview. An online questionnaire was also spread to collect more insights. This survey consisted of fifteen closed questions and four open questions.

## 4.5 Results

In order to analyse to what extent the illuminated biofeedback technique influenced the coherence in the group, two measures can be used. The first is the perception of coherence in the group. The second is the actual coherence of the heart rates.

The perception of the participants was positive. They were enthusiastic and cooperated well during the workshop. When asked their opinion after the workshop, the participants were positive about the workshop and the general idea of the technology. One participant mentioned watching the colours often:

> "With the breathing session I thought I had to watch my colours change, so maybe I was thinking too much during breathing. I wanted to see whether I could influence the colour because of my difference in breathing, so that might have affected the outcome a little bit."

Participants generally liked the group feedback, and found it fun to see how the colours synchronized with each other. One participant mentioned this helped feeling part of a group. However, participants also mentioned it was rather difficult to see the actual colour on the screens of other participants, since the colours got slightly distorted via Skype. Some also mentioned they found it difficult to focus on the different screens and on the exercises of the workshop both at the same time. Participants also indicated that holding the phone was challenging, and the flashlight tended to get hot. It was indicated that a system that would display the feedback directly on the monitor would be clearer.

From the questionnaire distributed after the workshop, participants indicated they liked the app. They understood the colours of the application, often saw their own screen change colour, and noticed the screens of others a little less. They indicated they felt comfortable in the group and generally did not feel exposed using the app. For most participants, the application increased the sense of belonging in a group. They also saw its potential for use in classrooms and indicated that the technology could make a group feel closer together, and it could be especially useful for teachers. Students would also get the opportunity to help each other when receiving feedback. One participant mentioned privacy as a concern in such a situation.

When asked to rank the feedback types, the group feedback was favoured the most, followed by true feedback, and finally no feedback. Almost half of the participants indicated that group feedback increased their sense of coherence in the group, and a third indicated increased sense of coherence for true feedback. With no feedback, one participant indicated a decreased sense of coherence.

From the heart rate data gathered during the workshop, no coherence could be found. Figure 3 shows one of the data plots. This graph displays the heart rates that occurred during the first workshop while having the group feedback mode enabled. Each line in the graph displays the heart rate data of one participant. The time on the horizontal axis is measured from the moment that the first participant logged into the specified mode. The error margins are determined by running the application on a phone, and comparing the readings with those from a smart watch. Due to issues during the third workshop, data from that workshop could not be used for analysis. Although the data of the other two sessions show some patterns that could indicate coherence, these are too limited to rule out influence of the exercises of the workshop or pure chance. From figure 3 a moment of heart rate synchronization can be seen just after minute 6. This coherent drop occurred during the emotion stimulation exercise of the workshop. However, whether this moment of synchronization was caused by the illuminated feedback cannot be proven. Synchronization of the heart rates could thus not be proven.

## 4.6 Conclusion

The aim of this study was to show whether group coherence could be achieved over an online connection, with the help of biofeedback technology. From the heart rate data gathered during the research, the occurrence of coherence could not be proven. However, the experience of the participants gave a positive result.

Participants generally liked the technology and could see its potential. They liked to see their colours change, and those of the other participants. When using the true feedback mode, participants indicated a small increase in coherence. Using the group feedback mode, more participants indicated an increased sense of coherence. Without any feedback, one participant sensed a drop in coherence. When asked their favorite display mode, group feedback was preferred.

Although it could not be proven that the technology is able to create a true state of coherence, some participants did sense increased coherence while using the technology. The research shows that the technique of illuminated feedback is able make the participants more involved and more

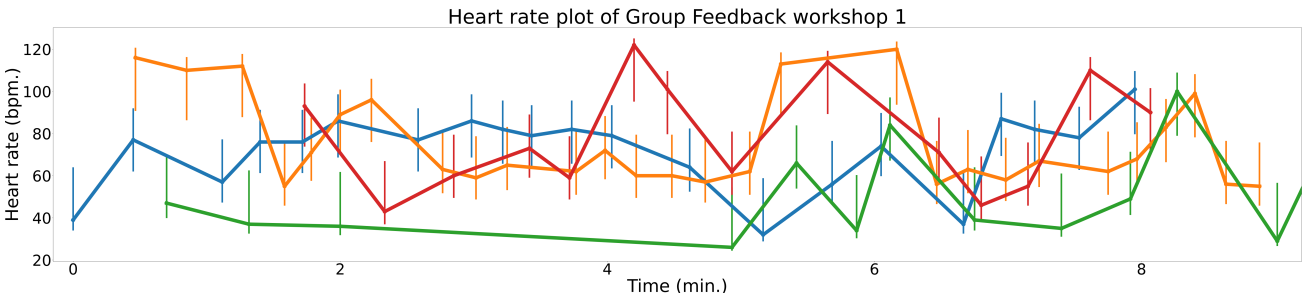


**Figure 3. Plot of the heart rate data gathered during workshop 1 with the group feedback mode**

aware of their own state and that of those around them. As mentioned in [21], the two most important factors for an engaged conversation are attentiveness and enthusiasm. When the illuminated feedback technique enhances these factors during conversations, users could already feel more physically together.

# 5. DISCUSSION

This paper introduced a technique that could bring enlightenment to students during homebound schooling. It focused on the application of illuminated biofeedback for students via online means.

In order to provide biofeedback to a group of people, a means was chosen which could provide the feedback to an entire group at once: illumination. Besides the ease of sharing, illumination can also make use of different colours. Colour has been proven to influence people's affect, cognition and behaviour. Combining these effects with the benefits of biofeedback could provide strong influence, in a subtle manner.

Biofeedback in general has proven to be effective for improving mood, reducing anxiety, increasing self-awareness and enhancing the sense of coherence in a group. HRV-biofeedback training has even resulted in a state of heart coherence for a group of students. Additionally, biofeedback research on students has been extensive, thus it can be concluded that the effectiveness of the technology is similar for this age group. Also for applying the technique online, studies have shown that several benefits can be reached. However, it should be mentioned that research on this area is still limited.

From the literature review in this study, it can be concluded that there is good evidence that applying illuminated biofeedback during online lectures can help sooth stressed students, and make students feel more coherent.

The questionnaire distributed in this research confirmed that students generally feel more lonely during homebound schooling and struggle with the need of additional self-discipline. When introducing illuminated biofeedback to the students, most found it intriguing and could get used to it. However, students also indicated they would feel uncomfortable sharing their emotional state. Again privacy was mentioned as an issue. Students also indicated they would prefer group level feedback over individual feedback. Perhaps a system that would combine both techniques of group feedback and true feedback could be designed, where the true feedback is private to that student, and the group feedback can be shared.

The exploratory user study has shown that the use of illuminated biofeedback can increase the sense of coherence in a group. Again, group feedback was favoured and resulted in the highest increased sense of coherence. From the heart rate data gathered it could not be proven that actual coherence occurred. Participants were generally positive about the technique, provided that no additional equipment would be needed for measurement. This could be solved by using facial expression recognition software.

# 6. CONCLUSION

The aim of this paper was to investigate whether the use of illuminated biofeedback in an online classroom would help the students, or hinder them.

From the existing literature it can be concluded that illuminated biofeedback has potential and would be of help during online classes. By increasing the sense of coherence in online classrooms and soothing stressed students, the technology can provide support during lectures in an unobtrusive manner.

However, from the several user studies conducted - and from the questionnaire and exploratory study in this research - the answer seemed not to be that simple. Subjects often indicated to feel uncomfortable sharing their emotional state, and mentioned concerns regarding privacy. If such a system would thus be deployed in a classroom, this sense of exposure has to be resolved.

This, again, does not imply that the technology could better not be deployed. Since the mental health of many students is deteriorating during homebound schooling, not deploying a supporting technology could result in the mental suffering of many students.

Developing a technology that could both deliver the benefits of biofeedback and meet the students who would otherwise feel exposed requires additional research. Although homebound schooling seems to be something temporary in the current COVID-19 outbreak, a more prominent step towards online education will inevitably be taken in the future. Therefore it is of importance that this technology will be ready to assist.

# 7. LIMITATIONS

This research was set up as an exploration of the field of illuminated biofeedback online. Although intriguing results were obtained from the studies, both the survey results, as the user study have their limitations.

For the survey, the sample size was too small to create statistical significance. Furthermore, the population consisted fully of students from The Netherlands, thus the results cannot be generalized for students in other countries. Finally, it is estimated that around a quarter of the respondents are students from the University of Twente, which might also limit the generalization.

Regarding the user study, statistical significance could also not be reached, due to its small-scale exploratory nature. Due to a lack of available subjects, participants were not all students. Also, the study had more male participants than female participants, and the different ethnic backgrounds could be of influence on the communication and feeling of coherence in the group, also since English was not the first language of most participants. Although the background of the participants varied, it is not certain to what extent these results can be generalized.

Furthermore, the accuracy of the developed application is error sensitive. It could be that the accuracy of the readings varies across devices, or that erroneous readings occurred when users moved their finger too much. Another problem encountered during the study, is that the participants found it rather difficult to show their screen properly, while having to hold their finger on the camera. This could have influenced the emotional state of the participants. The colours from the phone screens also got distorted when visible on Skype. This created some difficulties with interpreting these colours. Finally, there were some complications during the second and third workshop. Due to time constraints, the second workshop only consisted of breathing exercises. For the third workshop, one participant had to drop out and another failed to use the app according to the instructions given. The latter was not known until after the workshop.

Additionally, a very specific set of colours was chosen. The exact effects of these colours is not known, thus the re-

sults could have differed with the use of another colour palette. Also, since the participants had different ethnic backgrounds, these colours could have had varying effects on each participant [4].

## 8. FUTURE RESEARCH

Based on the results from this study, several directions for future research can be identified. The main direction is to see whether true coherence can be achieved over an online connection. Although this research showed an increased sense of coherence, it could not prove the presence of heart rate synchronisation. For this, several factors from the exploratory user study as presented in this paper should be improved. First, the technique should be tested on slightly larger groups, so that patterns in the heart rate data can be more easily detected. Second, the measuring device used should be easier to handle, in order to minimize distraction from handling the device. This could, for example, be done with facial expression recognition software. Also technologies that can measure actual heart coherence could be used to gain additional insights. Third, all subjects should be students. Also the activity content of the research could be changed, since this might have influenced the sense of coherence in the group as well. Furthermore, multiple sessions could be run with the same group, to see whether coherence will increase over time, or whether the subjects will react differently to the technology over time.

Other researches related to this study can be identified as well. One is to verify whether online group coherence can be achieved without the need of extensive training. Many of the researches conducted related to heart coherence were only able to achieve this state with the help of several hours of training [7, 8, 25, 29, 54]. When training is indeed required, the deployment of the technique in online classrooms requires some attention, perhaps in the form of an introduction lecture. Since it was also found in this research that many students would feel exposed while using the technique, it might be necessary to always have an introduction lecture, where students are introduced to the technique and the benefits it can bring. Researching the effects of receiving such information is thus also of importance. Another related area that can be researched is to see what other forms of biofeedback can be used during online classes. Perhaps these other forms require less training than illumination, or will be more effective. Also the colour palette used with the illuminated feedback could be of influence. Running multiple user studies with different colour schemes could show a difference in effectiveness.

The questionnaire in this research also showed that many students are sceptic about the use of illuminated biofeedback. Additional research should be conducted on the effects that scepticism can have on the coherence in a classroom. These students might badly influence the ambiance and reduce the effectiveness of the system. Additionally, it should be researched what would be the best way to educate students about this technology, so that the sense of scepticism fades.

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