ANALYZING STUDENTS' EMOTIONAL STATES DURING PROBLEM SOLVING USING AUTOMATIC EMOTION RECOGNITION SOFTWARE AND SCREEN RECORDINGS

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Emotions play important part in mathematical problem solving, yet the theories of their role are still at their preliminary stages. In our study, we introduce a method, where screen recordings and automatic emotion recognition software are used to study the emotional states of five upper secondary school students during a solitary GeoGebra problem solving session. Common emotional states during problem solving were neutral (40 % of time), sad (34 % of time), happy (15 % of time) and angry (8 % of time). Different phases of problem solving were emotionally different, non-neutral emotional states being most prevalent during decision points such as using the undo button. The method used opens possibilities for new kinds of research designs for studying the role of emotions in problem solving.

INTRODUCTION

Affective elements have received much attention in the literature of mathematics education in general and problem solving in particular (e.g. McLeod & Adams 1989, Schoenfeld 1985, Leder, Pehkonen & Törner 2002, DeBellis & Goldin 2006). However, the majority of studies have focused on relatively stable traits in the affective domain, such as attitudes, beliefs and values. Considerably less attention has been given to emotions, defined as “rapidly changing states of feeling experienced consciously or occurring preconsciously or unconsciously during mathematical (or other) activity” (DeBellis & Goldin 2006, p. 135).

Emotions are influential in the key moments that determine the success of solving a problem. Goldin (2000) uses the concept of *affective pathways* to describe how the typical patterns of emotional states lead to successful or unsuccessful problem solving behavior, and in the long run partly shape one's attitudes, beliefs and values concerning mathematics. However, proper understanding about the role of emotional states requires further research.

Studying momentary emotional states is typically work-intensive and therefore the number of subjects in such studies is often small. In this report, we introduce a method that automatizes part of the work and thus opens possibilities for new kinds of research designs: we use screen recording technology to capture student’s computer-aided problem solving process and automatic emotion recognition software to analyze student’s emotions during the process.

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Phases of problem solving

For research purposes it is often useful to identify different phases of the problem solving process. Several models of phases or stages of problem solving have been introduced by different authors (e.g. Polyá 1945; Mason, Burton & Stacey 1982; Schoenfeld 1985; Hähkiöniemi, Leppäaho & Francisco 2013). Polyá's (1945) model with four phases – *understanding the problem, devising a plan, carrying out the plan and looking back* – is most widely recognized, but it is intended to be rather a guide to a problem solver than a research tool. Although the same applies to Mason's et al. (1982) model, they importantly point out that problem solving process doesn't necessarily proceed linearly along the phases but the solver might for example return to make sense of the problem after some new information has occurred to him or her.

In his studies, Schoenfeld (1985) used transcriptions of students' discussions during problem solving to identify the phases of problem solving. He distinguishes six phases in problem solving: *reading, analyzing, exploring, planning, implementing*, and *verifying*. Essential to his model are also decision points – moments in the problem solving process when a student should use metacognitive skills to decide on further actions. For example, when new information concerning the problem occurs to the student, he or she must consider whether the current attempt to solve the problem is still valid or should a new strategy be used instead.

The two main approaches to collect data on student thinking during the process of problem solving have been *think-aloud* and *stimulated recall* methods. However, as Hähkiöniemi, Leppäaho and Francisco (2013) indicate, it is possible to study problem solving with computer software using only screen recordings as the base for analysis. Hähkiöniemi et al. (2013) investigated problem solving with dynamic geometry software GeoGebra. They found none of the previous models of problem solving directly applicable, and thus developed a new classification, consisting of five phases: *framing the problem, exploring the solution, conjecturing, investigating the conjecture*, and *justifying*. There was great variation between students on how they moved through these phases: some students proceeded linearly from phase to phase, but most of them skipped phases and/or returned to previous phases during the process.

In present study, an adaptation of Schoenfeld's (1985) model is used. Instead of discussion or think-aloud transcriptions, screen recordings are used to conduct the analysis, similarly to Hähkiöniemi's et al. (2013) study.

Emotions and problem solving

There is a general agreement that emotions have an important role in human learning and mathematical problem solving specifically (Hannula 2012). However, theories about the role of emotions in the process of problem solving are still at their preliminary stages (Lehman et. al. 2008, Goldin, Epstein, Schorr & Warner 2011).

It is well established that emotions direct attention and bias cognitive processing. For example, fear (anxiety) directs attention towards threatening information and sadness (depression) biases memory towards a less optimistic view of the past (Power and Dalgleish 1997). There is also indication that positive emotions promote the creative aspects of problem solving, while negative emotions facilitate the reliable memory retrieval and performance of routines (Pekrun & Stephens, 2010). In mathematical problem solving, curiosity, puzzlement, bewilderment, frustration, pleasure, elation, satisfaction, anxiety, and despair have been observed to have important self-regulative functions (DeBellis & Goldin 2006).

There are several theories concerning emotion, emerging from different research traditions. In this paper, we follow the Darwinian tradition, where emotions are seen as products of evolution, they can be categorized to a small number of universal basic emotions (anger, disgust, fear, happiness, sadness and surprise) and these emotions can be identified from facial expressions (Ekman & Friesen 1971; Ekman 1992). This approach allows us to use Facial Action Coding System (FACS; Ekman & Friesen 1978) to identify emotions from students' facial expressions. The process of identifying emotions has traditionally required trained human coders, but during last few decades, automated computer methods have been developed (Bettadapura 2012).

There is some evidence that basic emotions would be rare in learning context. (Craig, D'Mello, Witherspoon & Graesser 2008; Lehman, D'Mello & Person 2008). Therefore, alternative emotion classifications that would suit better the learning setting have been developed. Both Craig et al. (2008) and Lehman et al. (2008) used a learning-centered emotion classification consisting of anxiety, boredom, confusion, contempt, curiosity, eureka and frustration. Pekrun and Stephens (2010) describe a model for emotion in achievement setting, which includes enjoyment, relaxation, anger, frustration, boredom, hope, joy, relief, anxiety, hopelessness, pride, gratitude, contentment, shame, sadness and disappointment.

Hannula (2012) suggests that achievement emotions can also be looked through six basic emotions. Enjoyment, hope, joy, pride, and gratitude are different variants of happiness, whereas boredom, hopelessness, sadness, and disappointment are variants of sadness. Frustration is a variant of anger and anxiety a variant of fear. Relaxation, relief and contentment do not present any basic emotion, but they can be seen as removal of a negative emotion. (Hannula 2012).

In this study, our aim is to find out, how different basic emotions occur in different phases of problem solving. Another important aim is to investigate, how our research methodology, which combines screen recording and automatic emotion recognition, works in the context of mathematical problem solving.

METHODS

Data collection

The data for this study was collected in a Finnish upper secondary school in Helsinki. Participants were five students (two girls, three boys) participating in the advanced mathematics syllabus. Each student separately participated in a session lasting about one hour, of which 20 minutes was devoted to problem solving. The session consisted of getting acquainted with the dynamic geometry software GeoGebra (Hohenwarter, 2002) using a practice applet, working with a two-part mathematical problem using two GeoGebra applets, and discussing the process with the researcher.

The mathematical background of the problem was the circumscribed circle of a triangle. First part of the problem was to find out, whether a circle could be drawn so that it goes through three points, in three given situations. The following instructions were given:

> Let A=(-2,0), B=(0,2), C=(2,0), D=(0,0) and E=(3,-2). Is it possible to draw a circle so that the circle goes through a) A, B and C, b) B, C or D, c) C, D and E?

The GeoGebra applet provided with the problem included the points mentioned in the instructions, a coordinate system and a customized toolbar with following tools: *Move, Delete, Point, Perpendicular Line, Perpendicular Bisector, Angle Bisector, Polygon* and *Circle with Center through Point*.

In the second part of the problem, the GeoGebra applet contained the same toolbar but no coordinate system. Students were given a statement "It is always possible to draw a circle through three given points" and asked to either show that it is true or show that it is false.

Each student's screen was recorded during the use of GeoGebra applets. Integrated webcam of the laptop computer running GeoGebra was used to record a video of student's face. After the problem solving session, a video-based stimulated recall interview (e.g. DeBellis & Goldin 2006), was conducted and audio-recorded, but that data is not analyzed in this report.

Analyzing the screen recordings

We analyzed only the screen recordings of the two problems. Events on the screen were transcribed to a table with time codes. Transcriptions were read multiple times and similar events were grouped together. We ended up with the following event classes: *changes to next or previous applet, chooses a new tool, clicks the undo button, deletes an object, draws an object, explores the menu, holds the pointer still, moves a point and moves the cursor*.

To identify the phases of problem solving, the screen recordings were watched again, looking for phases described in the literature. By making interpretations of students' actions (Table 1), events representing Schoenfeld's (1985) characterizations of reading, analyzing, exploring, implementing and verifying could be found in the data. Moments when a student used GeoGebra's delete tool or the undo button, or changed to the next or the previous applet, were considered decision points. Each event in the transcription was encoded to belong to one of the phases or to be a decision point.

Student action	Phase
Student holds the pointer still above instructions	Read
Student holds the pointer still or moves it around without concentrating on any particular object	Analyze
Student draws objects, moves points or objects or explores the menu	Explore
Student performs a series of actions	Implement
After accomplishing a goal, student holds the pointer still or redoes the actions that lead to success	Verify
Student uses the delete tool, the undo button, or changes to next or previous applet	Decision point

Table 1: Interpretation rules for student actions.

Automatic emotion recognition

Noldus FaceReader 5 was used to recognize emotions from student's face videos. The software is based on the theory of basic emotions and it has been used e.g. in studies of usability (Goldberg 2012), intelligent tutoring systems (Harley, Bouchet & Azevedo 2012) and consumer behaviour (He, Boesveldt, Graaf, & Wijk 2012). FaceReader identifies key points in subject's face and classifies the emotions using an artificial neural network trained with manually notated images (Loijens & Krips 2014). In addition to six basic emotions, the classification includes an emotionally neutral state. As an output, FaceReader produces the intensity of each emotional state 10-30 times per second and the dominating emotional state at each time.

In our analysis, for each face video we first used FaceReader's automatic calibration and then ran the analysis. FaceReader state logs were used to add emotional data to the event transcription. Whenever multiple emotional states occurred during a single event, all the states were recorded (Table 2).

Time code	Event	Emotional state
15:34	Student draws an angle bisector at the intersect of the perpendicular bisectors of AD and BD	Sad
15:38	Student clicks the undo button	Sad/Angry
15:45	Student explores the menu	Angry/Neutral

Table 2: GeoGebra event transcription with emotional states.

All event-emotion combinations were extracted from the transcriptions and separately cross tabulated with the classifications of the event classes and phases of problem solving. A chi-squared test was calculated for both contingency tables.

RESULTS

Most common emotional states during problem solving were neutral (40 % of time) and sad (34 % of time). Happy (15 % of time) and angry (8 % of time) were also common, whereas surprised (3 % of time), disgusted (1 % of time) and scared (0% of time) were rare.

Cross tabulation of event classes and emotional states is presented in Table 3. Surprised, disgusted and scared with 12, 7 and 0 event-emotion combinations respectively were so rare that they were excluded from further analysis. Small expected frequency prevented using a chi-squared test.

Event-emotion combinations	Neutral	Happy	Sad	Angry	Total
Changes to next or previous applet	3	1	5	1	10
Chooses a new tool	25	16	30	7	78
Clicks the undo button	0	5	10	10	25
Deletes an object	3	2	3	3	11
Draws an object	24	17	29	7	77
Holds the pointer still	27	11	19	3	60
Moves a point	19	11	17	1	48
Moves the cursor	21	9	19	4	53
Total	126	73	139	41	379

Table 3: Contingency table of the event classes and the emotional states

The cross tabulation of the phases of problem solving and the emotional states is presented in Table 4. Different phases were emotionally different beyond coincidence (chi-squared test $p=0.004$).

Event-emotion combinations	Neutral	Happy	Sad	Angry	Total
Read	11	7	12	2	32
Analyze	21	3	10	3	37
Explore	58	42	70	20	190
Implement	19	1	20	4	44
Verify	10	6	11	2	29
Decision points	7	14	16	10	47
Total	126	73	139	41	379

Table 4: Contingency table of the phases of problem solving and the emotional states

DISCUSSION

Our results suggest, that although neutral was the most common emotional state in this study, also some of the basic emotions (happiness, sadness and anger) are common in problem solving. If achievement emotions, described by Pekrun and Stephens (2010), are looked through basic emotions as Hannula (2012) suggests, most of the achievement emotions are covered by these three emotional states.

Results also indicate that different events and the phases of problem solving are emotionally different. However, more research is needed to investigate these differences in detail. The method for classifying phases of problem solving used in this study, although being straightforward, includes multiple presumptions about student thinking.

Goldin (2000) suggests that emotions are in an important role during the key moments of problem solving process. This is in line with our findings about the emotional states associated with decision points (Schoenfeld 1985): the proportion of non-neutral emotional states (happiness, sadness and anger) was greatest during the decision points (Table 4).

CONCLUSIONS

The aim of this study was to use a combination of screen recording analysis and automatic emotion recognition to analyze students' emotions in different phases of problem solving. Our results, indicating that different phases are emotionally different, are encouraging and suggest that this kind of methodology can be used to study mathematical problem solving. More studies with a larger number of subjects are needed to further investigate the potential of this research design.

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