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Triangulation of Three Different Research Methods when Capturing Participant Data During Engineering Education

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Abstract

Designing new products and further developing existing products has become increasingly important for today’s industry. Therefore, engineering education has been extending from theoretical education towards hands-on, challenging project-based education. The aim is to teach students real-life problem-solving skills along with communication and teamwork skills, which are also essential in the future working environment after graduation. Tracking this learning experience efficiently is one of the critical steps for improving it. And industry around the world is increasingly interested and has incentives in measuring the effectiveness of the design process and the design team, as commercial product development and R&D are expensive, risky, and time-consuming.

In the experiment conducted in January 2016 in Geneva, Switzerland, the participants were from four different European countries and from several different study backgrounds. Most of them were participating the experiment as an elective part of their postgraduate studies.

The teams were challenged with a task to build a robot which communicates with the user, is easy to use, moves independently, and should be able to express four distinct emotions. The challenge lasted for 4 days and 4 hours. Data was collected and analyzed by using three different research methods; time-lapse images, time-tracking software operated by the coaches individually, and written coach notes.

The teams were tracked with eight time-lapse cameras and time tracker data was collected with software installed to coaches’ mobile phones. Coaches also made handwritten notes after each student interaction to elaborate details about the encountered issues. To synchronize with other methods, the notes also included a timestamp when the coach had helped the team.

Time-tracking data from coaches showed in detail, how much time the coaches had spent with the teams. There were only a few times when a coach made a mistake by forgetting to start or stop the timer. Without the alternative methods, this information would be quite hard to analyze since one could only see the duration of the session and time when it happened. Handwritten notes, on the other hand, did give an enormous amount of additional qualitative information about what kind of problems the teams were facing in their challenge.

The outcome of the study is that none of the three methods proved to be superior, but each one of them brings up useful data for future studies when combined. The paper will introduce detailed recommendations in building and updating such a measurement setup in a dedicated working space and analyze the gathered data in more detail.

Background

Engineering graduates' employers expressed their concern because new engineers lack the capability and preparation to define and solve open-ended problems and in response, engineering design was increased in education. [1] An approach to teaching design to engineering students is teaching problem-solving methods and product design processes that students may use to confront open-ended problems [2]. Many of these kinds of courses include hands-on learning experience to emphasize learning by doing [2]–[4].

In the challenge, held during an engineering design course, students get a brief and funny exercise that intends to give them an introduction to the field of mechatronics. The challenge lasted for 4 days and 4 hours and was included as part of engineering design course because the course projects were increasingly requiring more mechatronic skills. It is a common fact that some of the students have no experience in microcontrollers and coding, and therefore the teaching of coding starts from the basics.

For the students, this challenge is a great place to learn basic coding and find out how much it takes to build something with microcontrollers. The students' task is usually to create a simple robot using microcontrollers, sensors, actuators and frame-building material, which is usually paper or cardboard. The finalized robot has to have some sort of interaction with the user. [5] The specifications for the challenge were, that the robot needs to: communicate with the user, be easy to use hence don't need a user manual, be able to move independently, express four distinctive emotions. Emotions are the user-centric part of the challenge, and the goal is to communicate with a real person on an emotional level. The aim is to create interactions with the robot that are understandable to a human. This connects the challenge strongly to one of the core components in design thinking and user-centric design in general.

Methods

This paper is a part of a wider study to analyze and measure a wide range of metrics during a one-week educational workshop. The paper, and the post-graduate thesis it is based on, was intentionally focused sharply on the coaching time tracking and the various tools and methods that could make it efficient and accurate. The most important research questions for this paper are 1) how accurately the coaching time could be tracked and 2) how the different tracking methods could be improved in the context of the whole workshop.

The paper also introduces and touches a wide range of interesting areas of research, that will be taken forward as separate research streams by other participants in the research group, and thus not analyzed in the scope of this paper.

The 34 participants were from four different counties; five from Estonia, four from Italy, four from Norway and 21 from Portugal. Participants' nationalities were Estonians, Finnish, Italians, Norwegians and Portuguese. The age difference was from 14-year-old to 45-year-old. The average age of the participants was 25 years with a median of 24 years. 14 (41.2%) participants were women, and 20 (58.2%) were men. Participants' disciplines were mechanical engineering, electrical engineering, automotive engineering, civil engineering, industrial engineering, industrial design, graphic design, product design, equipment design, architecture, multimedia, business, three high school students, one middle school student and one unknown.

The participants were divided into nine teams. Seven of these teams were four-member teams, and two teams were three member teams. Teams were called Actinium, Americium, Curium, Einsteinium, Fermium, Lemmium, Neptunium, Nobelium, and Thorium, inspired by current and proposed elements . Teams were placed around the facility in a way that everyone would have their own working place, and cameras can capture their every movement.

Continuous time-lapse photos of teams designing, coding and building their PaperBot prototypes were taken with eight cameras. Two of those cameras were wall mounted static cameras installed to observe what is generally going on in the working space. Six of the cameras were temporarily installed action cameras. Time data was also collected manually with mobile phones as a second method to measure the time coaches spend with the teams. Each one of the three technical coaches had cell phones with a time-tracking software installed.

The main idea with the coaching was to help teams to find the solution for their problem and not to fix the problem for them straight away. If the team was not able to come up with the solution, the coach would correct the code and then help them to understand what he had done. Coaches were keeping notes and writing down problems teams had. This was done to get qualitative data to support the quantitative data measured with the time-tracking software.

Data

All six temporary installed action cameras and the two wall mounted cameras took a total of 178 833 photos during the challenge. Based on the data from pictures, coaches helped the teams a total of 20 hours 25 minutes and 59 seconds. The average time a coach helps a team was 21 minutes and 19 seconds and median 6 minutes and 50 seconds. Average of coaching per coach was 7 hours and 55 minutes and 53 seconds. Average coaching per day was 4 hours 45 minutes and 32 seconds. Resolution of the time-lapse was 10 seconds.

According to time tracker data, coaches helped the teams a total of 47 hours and 29 minutes. The average duration coach helping a team was 22 minutes and 26 seconds and median 12 minutes. Average of total coaching per coach was 15 hours 49 minutes and 40 seconds. Average of coaching per day was 9 hours 29 minutes and 48 seconds. Resolution of the time-tracking application was one minute and anything under one minute was not recorded.

From the total of 89 notes of the coaches, 79 helping situations were somehow technical, and the remaining 10 cases were help regarding where to get materials for building the robot and giving out components from a single distribution point, called Arduino Bazaar. From those 79 technological notes 62 cases were related to coding, and the rest (17 notes) were about helping the team with mechanical problems (such as soldering or replacing a broken sensor), problems with Arduino Software (crashing, not starting or not compiling) or general questions on how the sensor in hand can be used. And those 62 coding related notes can further be categorized into two groups. 35 helping situations on how to use a sensor, how to install a library to Arduino Software, how to use a servo and how to calibrate or fine tune it, and how to use LED strips. The remaining 27 notes were related to the structure of the code and coding logics, such as how to combine code, how to use functions and cleaning up the code.

A deeper understanding of the records and their qualitative value are to be studied in future research and therefore are out of the scope of this study.

Discussion

When looking at the time data, one can think that the method of using pictures recorded only half of the coaching situations, but this is not true. There are three main reasons why the picture data recorded fewer coaching sessions.

> **Firstly**, the number of photos to go through manually was enormous. And therefore, only pictures of six cameras out of eight were analyzed, the images from camera 7 and 8 will be analyzed in the future. The analyzed time-lapse covered seven teams out of nine.
>
> **Secondly**, the cameras were not working as planned. Camera 2 was barely taking time-lapse images at all, and several cameras had some sort of problem, or the cards ran out of memory (cameras 1, 3, 4, and 5). Camera 6 was the only one that functioned according to the plan the whole time, which was taking the time-lapse of team Curium.
>
> **Third** is that the teams were not always working in their dedicated working space, and therefore coaching happened around the premises. For example, team Actinium stopped using the dedicated space because the air quality wasn’t the best during the working period and some of the coaching done to this team happened in Arduino Bazaar (the coach headquarters).

Since some of the picture data is missing, only the data based on teams *Curium*, *Fermium*, *Lemmium*, *Nobelium*, and *Thorium* can be compared from both data sets. Tables containing data of these five teams are listed and compared below. The data of Curium, Fermium, Lemmium, Nobelium, and Thorium is presented here to make the comparison between the two methods easier. The percentage represents the proportional difference between the values measured from picture data and time tracker data.

TABLE 1 CURIUM, FERMIUM, LEMMIUM, NOBELIUM, AND THORIUM TIME DATA, PICTURE DATA

Coaching duration, picture data	**11.01.2016**	**12.01.2016**	**13.01.2016**	**14.01.2016**	**15.01.2016**	**Grand Total**
Coach 1		**0:55:18**	**0:39:20**	**0:24:30**	**0:15:40**	**2:14:48**
Curium		0:08:48				0:08:48
Fermium		0:46:30		0:24:30	0:15:40	1:26:40
Lemmium			0:39:20			0:39:20
Nobelium						
Thorium						
Coach 2		**1:20:36**	**1:25:02**	**3:32:36**	**4:52:42**	**11:10:56**
Curium		0:29:48	0:51:30	1:27:52	1:13:12	4:02:22
Fermium					1:14:20	1:14:20
Lemmium		0:37:28		1:36:30	2:22:50	4:36:48
Nobelium		0:13:20	0:33:32	0:28:14	0:02:20	1:17:26
Thorium						
Coach 3	**0:03:10**	**1:16:54**	**0:34:44**	**3:46:20**	**1:19:00**	**7:00:08**
Curium			0:11:20	1:20:20	0:17:00	1:48:40
Fermium	0:03:10	0:06:40	0:00:50	1:40:30	0:43:00	2:34:10
Lemmium		0:31:10	0:02:40	0:43:20	0:15:40	1:32:50
Nobelium		0:39:04	0:19:54		0:03:20	1:02:18
Thorium				0:02:10		0:02:10
Grand Total	**0:03:10**	**3:32:48**	**2:39:06**	**7:43:26**	**6:27:22**	**20:25:52**

TABLE 2 CURIUM, FERMIUM, LEMMIUM, NOBELIUM, AND THORIUM TIME DATA, TIME TRACKER DATA

Coaching duration, time tracker data	11.01.2016	12.01.2016	13.01.2016	14.01.2016	15.01.2016	Grand Total
Coach 1	**0:01:00**	**1:28:00**	**0:42:00**	**0:37:00**	**0:15:00**	**3:03:00**
Curium		0:13:00	0:02:00			0:15:00
Fermium		0:53:00		0:24:00	0:15:00	1:32:00
Lemmium		0:03:00	0:40:00			0:43:00
Nobelium	0:01:00	0:10:00		0:13:00		0:24:00
Thorium		0:09:00				0:09:00
Coach 2	**0:05:00**	**1:32:00**	**1:23:00**	**2:42:00**	**6:42:00**	**12:24:00**
Curium		0:30:00	0:50:00	1:24:00		2:44:00
Fermium					4:17:00	4:17:00
Lemmium		0:37:00		1:07:00	2:23:00	4:07:00
Nobelium	0:05:00	0:25:00	0:33:00	0:11:00	0:02:00	1:16:00
Thorium						
Coach 3	**0:15:00**	**1:43:00**	**1:18:00**	**5:17:00**	**0:38:00**	**9:11:00**
Curium			0:34:00	1:29:00		2:03:00
Fermium	0:15:00	0:08:00		2:57:00		3:20:00
Lemmium		0:48:00	0:03:00	0:44:00	0:38:00	2:13:00
Nobelium		0:47:00	0:41:00	0:05:00		1:33:00
Thorium				0:02:00		0:02:00
Grand Total	**0:21:00**	**4:43:00**	**3:23:00**	**8:36:00**	**7:35:00**	**24:38:00**

TABLE 3 COMPARING THE DIFFERENCE BETWEEN PICTURE DATA AND TIME TRACKER DATA BY COACH AND TEAM

Data % differences	11.01.2016	12.01.2016	13.01.2016	14.01.2016	15.01.2016	Grand Total
Coach 1		**37.2 %**	**6.3 %**	**33.8 %**	**4.3 %**	**26.3 %**
Curium		32.3 %				41.3 %
Fermium		12.3 %		2.0 %	4.3 %	5.8 %
Lemmium			1.7 %			8.5 %
Nobelium						
Thorium						
Coach 2		**12.4 %**	**2.4 %**	**23.8 %**	**27.2 %**	**9.8 %**
Curium		0.7 %	2.9 %	4.4 %		32.3 %
Fermium					71.1 %	71.1 %
Lemmium		1.2 %		30.6 %	0.1 %	10.8 %
Nobelium		46.7 %	1.6 %	61.0 %	14.3 %	1.9 %
Thorium						
Coach 3	**78.9 %**	**25.3 %**	**55.5 %**	**28.6 %**	**51.9 %**	**23.8 %**
Curium			66.7 %	9.7 %		11.7 %
Fermium	78.9 %	16.7 %		43.2 %		22.9 %
Lemmium		35.1 %	11.1 %	1.5 %	58.8 %	30.2 %
Nobelium		16.9 %	51.5 %			33.0 %
Thorium				7.7 %		7.7 %
Grand Total	**84.9 %**	**24.8 %**	**21.6 %**	**10.2 %**	**14.9 %**	**17.1 %**

Before the comparison between these five teams was done, it looked like the picture method wasn't even close to the same time as the time tracker data. But after removing the team's whose data collection was corrupted, the difference between the two methods is 17.1%. This difference can be explained by the reason three mentioned above; the coaches helped the teams away from their working space in areas that are not included in the pictures.

Based on this small difference, which can be further improved with more extensive camera coverage, time tracker and picture data can be considered equally reliable a quantitative metric, but they are clearly missing the information on what participants were asking and what kind of problems they had during the challenge. On the other hand, note collecting method gives a good insight on the problems but has a major reliability problem with timestamps. By using note collecting together with either the picture or time-tracking method provides precise time information with good qualitative data. Still, the resolution of the time-tracking method was only one minute in this study, and therefore picture method offers six times better resolution when measuring time. Picture method can measure data only in the areas where the cameras were installed. The comparison shows that none of the tested methods are entirely reliable as a single tracking method, but if all the methods are combined, the quality and reliability of the data increases significantly.

The outcome of the study is that none of the three methods are superior, but each one of them brings up useful data for future studies when combined. The two different methods of tracking time can cover gaps in each other, and the coach notes add a lot of qualitative depth to the analysis. As a conclusion to this study can be said that none of these three methods would provide quality data alone, but in combination, they help to triangulate deeper understanding about the learning experience.

Conclusion

Data was gathered in three different ways, and the goal was to find out their strengths and weaknesses. Each one of the methods tells a different story about how much the coaches were helping the teams, and what kind of problems the teams were having. Collected data shows that the use of coach help was increasing daily towards the deadline. Also, our perceptions about understanding the roles of the coaches were clear for the team. If this kind of methods will be implemented in the corporate world in the future, clear roles for coaches will be necessary.

Pictures did give accurate information about when the team was in their dedicated working area, but this data had to be gathered manually by going through the pictures one by one. If there would be a satisfactory way of tagging the participants with beanies, vests or RFID tags, this data collection could be done automatically with a computer. This data could not have been collected with time-tracking software because that would mean a commitment from the participants by pressing start every time they arrive and stop as they leave their working place. This method would probably end up messing the data since the participants would probably forget to start or stop the timer. Therefore, this data needs to be somehow collected automatically.

Pictures were also a way to find out how much time coaches spent with the teams. It was an accurate and good way to collect this kind of data when going through the pictures manually. The fact is that with people staying in front of the camera, other orange colored interior elements or even furniture in the spaces messed up the possibility to gather data automatically with computer vision.

Time-tracking data was time data about how much time the coaches were spending with the teams. There were only a few times when a coach made a mistake by forgetting to start or stop the timer. It is believable that the fact only three coaches were using this time-tracking, and each of them had their personal mobile phone are the reasons why there were no more forgetting. Alone this information would be quite hard to analyze since one could only see the duration of the session and time when it happened.

Notes, on the other hand, did give an enormous amount of additional qualitative information about what kind of problems the teams were facing in this challenge. The problem was that there was not an established way to write these notes. Finding a pattern from well-structured and well-written notes that would follow a template would be easier. From the notes written by coaches, it can be inferred that the participants were mostly at a suitable skill level for this type of exercise as the meaning of the challenge is to teach basic skills on coding with microcontrollers.

Future study

During this study, our research group discovered several different topics and questions for future studies, that would be interesting to test and which will also benefit from the participant data validation offered by this paper. The topics are:

1. How the time and the way coaches helped the teams reflects the team's design outcome?
2. How much team members helped each other? From the pictures, it was clear that teams were asking each other for help during the challenge. How much the other team members helped and how much it helped, would be good questions for this kind of a study
3. How did the code written by the participants evolved during the different stages of the challenge and can this be reflected to measure what the participants learned during the challenge?

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