Evaluation of Textual Feedback for Incorrect Usage of an Augmented Reality Application

Julian Lüken, Mehmed Mustafa, Jan Schneider,
Steffen Tunkel, Chris Warin

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Georg-August University, Göttingen

Abstract

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Introduction

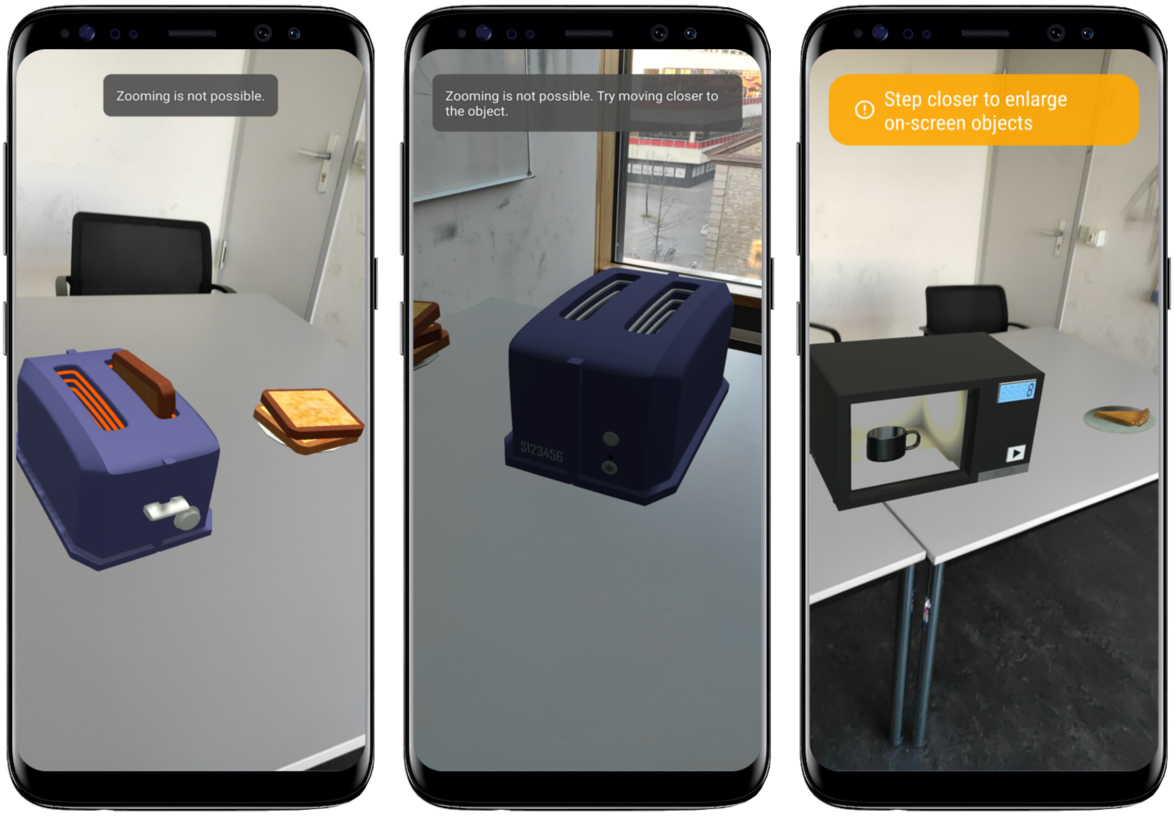
In recent years, the number of available mobile Augmented Reality (AR) applications for smartphones has increased [6]. Although mobile AR technology is no novelty, it was not widely available for society until a variety of smartphones were capable of running AR applications. Since most users are newly discovering AR technology, they don't know how to use its features yet, thus using unsupported gestures as input, which leads to frustration. Our main motivation for conducting this research is the lack of good feedback in case of incorrect usage, which could help a lot of users to avoid repeating common mistakes while using AR applications for smartphones. Providing good feedback could also help and teach users to control such AR applications without the need of a separate introduction.

Our research goal is to provide appropriate feedback to unsupported gestures and decide what type of textual feedback is the best. For validation of our approach we conducted a usability case study.

The organization of the paper is as follows. The section Foundations gives information about usability in general and the AR environment we provide the feedback for. In the section Related Work we discuss similar work on AR and feedback done in the past. The Approach section gives a detailed illustration of the feedback we present to users. In the section Case Study, we talk about the setup case study we conducted in order to validate our approach, followed by our results and the discussion thereof. Lastly, we summarize and conclude in the Summary and Outlook.

Foundations

Since the main goal of our work presented in this paper is to find suitable user feedback for augmented reality environments, we will further clarify what AR means and which technologies we used. AR itself describes a variety of technologies that place 3D virtual objects into a 3D real environment in real time, for example via a handheld device like a mobile phone (mobile AR) or using wearable goggles like the Microsoft HoloLens. In this paper we focus on AR for mobile phones, where recorded imagery of the phone is being augmented and shown to the user to display a mix of virtual objects and the real world at runtime.



(A) **(B)** **(C)**

Figure 1: Three screenshots of an app made with the Vivian framework

A virtual prototype is a ”[. . .] *computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model.”* [7]. The Vivian framework is an extension for Unity3D, that can be used to create mobile AR implementations of prototypes using a 3D model and one or more finite-state machines. (sauce?)

In a mobile app made with the Vivian framework, all user input relies on one finger gestures on the touch screen. In the example in Figure 1 (A and B) we can observe a 3D model of a toaster projected onto a live video of a real world scenario using Vivian. The user can interact with the different 3D models on the screen. Buttons can be pressed by simply tapping the screen where the respective button is displayed. Knobs and levers can be moved by putting a finger on the screen where the knob or lever is displayed, moving the finger on the screen until finding the desired position, and removing the finger from the screen afterwards. We refer to this gesture as *drag-and-drop.* The Vivian framework makes a clear distinction between movable and non-movable objects in a scene. The slice of bread in the aforementioned example is movable, whereas the toaster itself cannot be moved. Movable objects can be moved in the same fashion as a lever. To cover greater distances, one can move the device itself while dragging the object. Rotation similarly requires the user to hold their finger on the object and rotate the device until they find the desired orientation. The limit of one-finger-interactions exists due to the peculiarity of AR environments where two-finger-interactions (like a pinch zoom or a two-finger-rotation) would be contradicting with the intended design of such an environment. If one wants to take a closer look at the previously mentioned toaster for example, they would need to step closer to the toaster.

To evaluate different types of feedback, we decided to use usability testing as a tool to quantify the corresponding results. According to Nielsen, *”usability is a quality attribute that assesses how easy user interfaces are to use. The word ”usability” also refers to methods for improving ease-of-use during the design process.”* [4]. While usability testing refers to a *”observational methodology to uncover problems and opportunities in designs”* with the goal to identify problems in the design of the product or service, uncover opportunities to improve and learn about the target user’s behavior and preferences [2]. Therefore we chose to have the users fill out a System Usability Scale (SUS) questionnaire which we tailored to fit our needs. The basic SUS consists of ten questions regarding a systems usability. We added a few questions which target the feedback more as well as an open feedback item, where the participants were able to share their thoughts on the system with us.

Related Work

The topic of error handling in AR-applications has not been broadly studied yet. There are several guidelines on how to handle wrong user input. Microsoft states in its design guidelines, that error messages should alert users of an already occurred problem. Another point they make is that the message should be suppressed if it does not make the users change their behavior or perform an action [1]. In addition to that, Nielsen’s *Error Message Guidelines* demand error messages to be phrased politely. This is to avoid the implication that the user did something stupid or inherently wrong. It is also important that the messages are precise descriptions of exact problems, offering constructive advice on how to fix the problem [3]. A 2002 IEEE article discusses two approaches of how user help might be implemented in AR environments. What they did was to offer an icon which the users might activate themselves when they seek advice for a given task. The other feature was an automated help message that pops up when the user moves an object associated to a certain task closer to his face and tilts it. They state, that "[t]*his approach is more suitable for AR interfaces than traditional desktop help systems, which either distract users with a constant barrage of help messages or interrupt their work by making them search explicitly for help."* [5].

Approach

In order to find feedback in response to incorrect usage of a mobile AR application, we have to define what kinds of gestures we consider incorrect in the first place. The user interface provided by the Vivian framework is based on one finger inputs (see Foundations), therefore we should take into consideration each input that is not done with a single finger. Prominent examples for multiple finger gestures are the *pinch zoom* and the *two finger rotation*. The pinch zoom is a gesture in which two fingers are placed on the touch screen and moved apart in opposite directions. The two finger rotation is a gesture in which two fingers are placed on the touch screen also and are together moved clockwise or counterclockwise about the center of the positions of the fingers. Common misconceptions by inexperienced mobile AR users might include using said pinch zoom to either zoom in on objects or to bring them closer, or using two finger rotation to rotate objects.

To make users quickly and easily understand the controls of Vivian-based apps, we extended the Vivian framework to provide three feedback message implementations that differ in content, colors and size. The content of the first feedback implementation is a *critique*. If the user inputs a gesture that we consider incorrect, the app outputs a message that said input is not possible. For example, if a user tried pinch zooming, they would receive a message saying: "Pinch zooming is not possible". The content of the second feedback implementation is *critique* and *support*. We therefore refer to this feedback type as *combined* in the course of this paper. The user is provided with a message stating that above mentioned input is not possible and hinting them towards what they should try instead. In the scope of the previous example, such a message would say: "Pinch zooming is not possible. Try moving around the object." In the first two implementations, the messages have the same size and color scheme (see Figure 1, A and B). The third implementation is more concise *support*. For our previous example the exact message is saying: "Step closer to enlarge on-screen objects." It also differs in color scheme and size (see Figure 1, C). Each feedback message in every implementation is displayed for 5 seconds.

	Description	Gesture (input)	Response (output)
#1	critique	two finger rotation	Rotating the object is not possible.
		pinch zoom	Zooming is not possible.
#2	combined	two finger rotation	Rotating the object is not possible. Try moving around the object.
		pinch zoom	Zooming is not possible. Try moving closer to the object.
#3	support	two finger rotation (movable object)	Hold the object and move the phone to rotate
		two finger rotation (elsewhere)	Move around the objects
		pinch zoom	Step closer to enlarge on-screen objects

Table 1: The responses for each input in each implementation.

The contents of each message can be found in Table 1. The description column holds the names we assigned to the three different feedback implementations. In the gesture and response columns you can find the corresponding inputs and outputs respectively. If for example a user tried a two finger rotation in the critique implementation, the app would display a message saying "Rotating the object is not possible". In the support implementation we made the distinction between two finger rotations on movable objects and elsewhere. If the aforementioned center point of the two finger rotation is placed on a movable object (see Foundations), the app displays the message that corresponds to "two finger rotation (movable object)". If the two finger rotation is executed elsewhere, the "two finger rotation (elsewhere)" message is displayed instead.

Case Study

To evaluate the quality of our feedback implementations we conducted a case study in the domain of usability engineering, which is presented in this section. In the section "Setup of the Case Study", we describe in detail what each participant in the case study had to do and what data we collected. The results of the study are found in Results of the Case Study and afterwards discussed in Discussion of the Case Study Results.

Setup of the Case Study

In order to evaluate, which variant in our approach works best, we created two different prototypes with the Vivian framework (see Foundations). Both of them are quite simple kitchen devices: a toaster prototype and a microwave prototype (as seen in Figure 1).

The microwave's functionality is limited to heating an object inside it with constant power. Figure 1 C shows this prototype in an application. It has one button to add 10 seconds to the heating duration and another one below to open the door. The door can be closed by moving it. The status of the microwave is visually indicated by a small display showing the remaining heating time or "ready" in idle mode and a light inside the device, which turns on when it is heating or when the door is opened. A serial number is printed on the back of the microwave. The prototype scene is completed by two additional objects. A cup that is already in the microwave when the application launches and a piece of cake on a plate next to it. These objects are moveable by the user.

The toaster can toast one or two pieces of bread at a time. Figure 1 A shows the front of the prototype in an application and figure 1 B its back. The toasting can be started by pulling down a lever at the front and stopped by pushing it up again or by pressing the stop button, which is on the back. Otherwise, the toasting stops automatically after a time which is defined by the position of a rotatable knob at the front. The time mode is divided into low, medium and high duration. Further functionality is provided by the unfreezing mode, which can be activated using the snowflake button on the back. The activation of the unfreezing mode results in a longer toasting duration and is indicated by a light above the button. The toasting process itself is displayed by the glowing of the heating elements, which is visible in figure 1-A. The toaster prototype also has a serial number on its back. The prototype scene is completed by a stack of 3 pieces of bread lying next to it.

Based on these functionalities we designed three tasks per prototype, which are shown in Table 2. The tasks are increasing in complexity. An example of this increase is that in task 2 of the microwave we ask to heat the cup, which is already in the microwave, for any amount of time. Therefore, only the start button has to be pressed once to fulfill this task. Afterwards, in task 3, we ask to replace the cup with the pie and heat for a specific amount of time. This task contains more necessary steps: opening the door, moving the cup out, moving the pie in, closing the door, pressing the start button multiple times and finally pressing the stop button after the desired amount of time.

#	**Microwave**	**Toaster**
1	Read serial number of the microwave	Read serial number of the toaster
2	Heat up the cup	Toast the bread
3	Remove the cup, put the pie in, set the timer to 20 seconds and remove the plate at 5 seconds	Toast the bread on high heat and put the toaster in unfreezing mode

Table 2: The tasks for the different prototypes.

For the case study, we divided the participants into four groups. Each of these groups tested one version of the app on a mobile phone. The versions differed in the feedback given (see Approach). We gave no feedback at all to the participants in group 0, which is our control group. Participants in group 1 got our first implementation with *critique* feedback. In group 2 they got our second implementation with a *combined* feedback version and in group 3 they got our third implementation with *supportive* feedback (see Table 1). Each participant was asked to fulfill the tasks for each prototype in the order provided in Table 2. One half of the participants were asked to do the tasks of the toaster prototype first, while the other half did the tasks for the microwave prototype first. This divide was equally for all groups. We were able to evaluate subgroups with a certain implementation level and a certain order of prototypes they tested. In the following, the subgroups are named *TM*, which translates to "first toaster, then microwave" and *MT*, which translates to "first microwave then toaster", followed by the number of their feedback group. For example, a participant who was assigned the toaster first and then the microwave without any feedback was in the subgroup TM0.

Before the start of the test, we gave every participant a short introduction. This introduction contains information about the mobile AR technology and reasons behind usability testing to prepare the participants and create a similar level of expectation. It deliberately does not contain information about how to use the application or the scope of the case study. This is important so the participants are not biased about wrong usage and the feedback they would get. During the test, we used screen recordings to measure each participants' use of the application. These enabled us to acquire completion times for the different tasks and count the number of incorrect usages. We used a notepad to register further observations.

Following the test of the application, the participants were asked to fill in a questionnaire. This questionnaire consists of 3 parts. First we asked participants if they had used AR applications before. The second part is an SUS (see Foundations) about the usability of the AR application, that we tailored for our needs. The third part is an open question directly aimed to the feedback provided by the application, namely: *"If you have any suggestions on what kind of feedback from the app you would find better, please let us know"*.

Results of the Case Study

We conducted the case study with 10 participants per feedback group. This leads to 40 people participating in the case study in total. The smallest subgroups, defined by implementation and task order, were still filled with 5 participants. 21 of the 40 participants said they had prior experience with AR applications. The group with the highest prior knowledge was the control group with 7 of 10 participants. The groups for the *critique* feedback and the *combined* feedback both had 6 participants with prior knowledge, while the group with the *support* feedback had just 2 participants, who said they had prior knowledge.

In our approach, we consider especially two gestures as incorrect usage: the pinch zoom and the two finger rotation (see Approach). With the setup of our case study, the two finger rotation appeared more often than the pinch zoom gesture. Figure 2 shows the appearances of two finger rotations and pinch zooms for all tasks given to the participants in the case study. In total over all participants and all tasks, two finger rotations appeared 225 times, while pinch zoom appeared 51 times. Since 82% of the incorrect usages are two finger rotations, the results of our case study focus on those. We especially evaluate the second task for the toaster, since it was most demanding for the users. As shown in Figure 2 A, 91% of the overall two finger rotations occurred in that task. Also the majority of pinch zoom gestures occurred there.

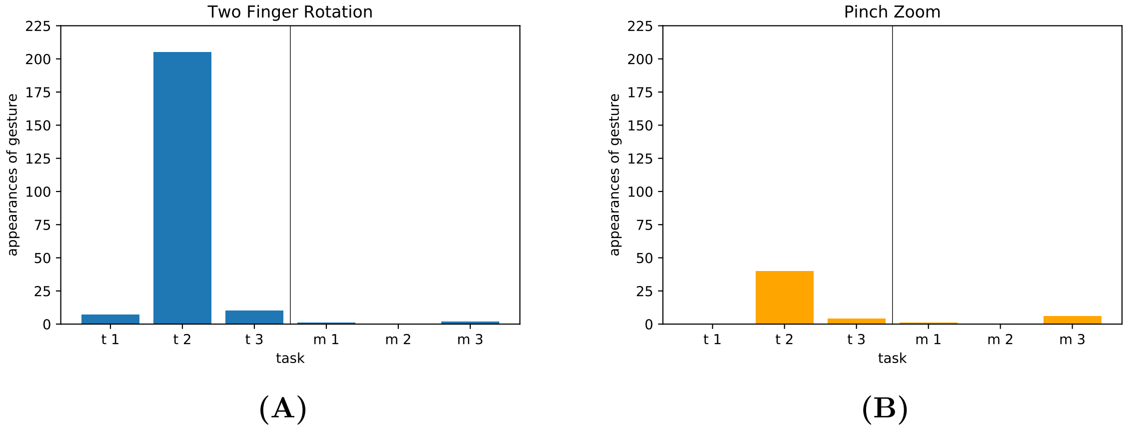


Figure 2: Appearances of the two finger rotation gesture and the pinch zoom gesture per task of the case study.

To evaluate the effectiveness of the different implementations, we compare the users' behavior for the second task of the toaster, with different measures. Figure 3 shows box plots for the two most important measures. The diagram in Figure 3 A gives the time participants needed to fulfill the task by their case study group. The median is given by the line inside the box. The box itself gives the 25 percentile on its lower bound and the 75 percentile on its upper bound. The whiskers are defined by the last data points which are within the range of 1.5 times the IQR. For clarification the data points are printed semi-transparent over the box plot. Figure 3 B is similar: it shows the two finger rotation attempts per user for the different case study groups. Important for this graph is that users, who had zero two finger rotation attempts, are excluded from the statistic. The reason behind it is that these users didn't receive any feedback message independently of their given implementation. To trigger any feedback, an incorrect usage must occur at least once. In total, 4 of the 40 participants didn't try any two finger rotations on this task. The maximum number for one specific implementation is 2. That means that for each implementation at least 8 participants' data was used to take the statistical values.

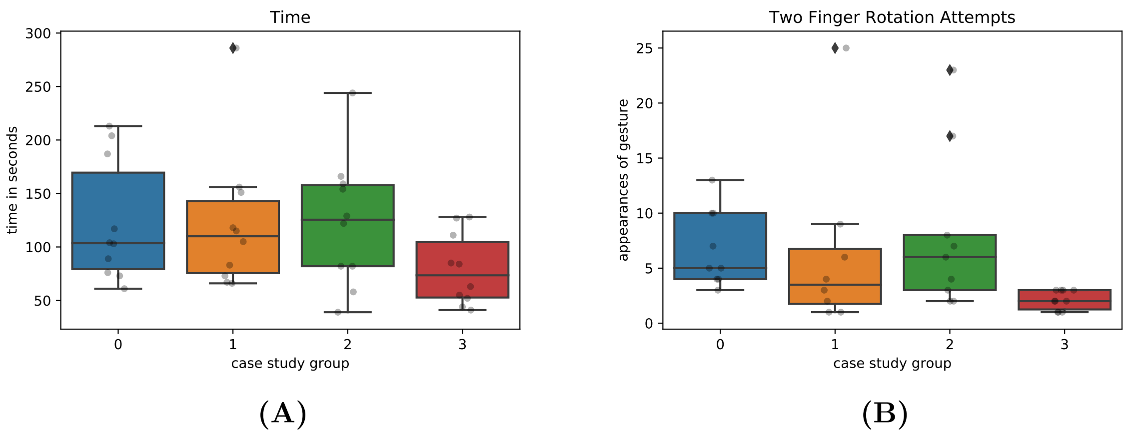


Figure 3: Evaluation of the two finger rotation attempts and time needed for the 2nd task for the toaster prototype.

To check whether the result is statistically significant, we performed statistical tests on both the time needed to complete the task and the number of two finger rotation attempts. The main test is the *Welch t-test*, that is used to compare the different implementations with the zero group, which didn't receive any kind of feedback messages. The *Welch t-test* has the assumption that both populations are normally distributed. We used the *Shapiro-Wilk* test on the residuals between the given implementation group and the zero feedback group. Generally we consider p-values below 0.05% as statistically significant. Figure 4 shows the p-values of the tests for the implementation with *supportive* feedback (used by group 3). We focus on these results because the mean values of these implementations' metrics implicate the biggest difference to the zero feedback group. Since all of the p-values of the *Shapiro-Wilk* test are above the threshold, the normality assumption for the *Welch t-test* holds. The result of the *Welch t-test* for the number of two finger rotation tries in task 2 of the toaster implies a significant difference to the zero group, which however cannot be confirmed by our result for the completion times for the task. [not done]

```
normality tfr diff:  0.9708724021911621
normality time diff: 0.5073676109313965
Welch tfr:  0.010198448041868305
Welch time: 0.05448460045107597
```

Figure 4: DUMMY: p-values for Shapiro-Wilk test and Welch t-test with both metrics

In addition, we evaluated the relationship between our two metrics for the task. The correlation coefficient between the time and the attempts of two finger rotation is 0.43, which indicates a moderate positive relationship between the metrics. Figure 5 visualizes the relationship between the time needed for the task and the number of two finger rotation tries. The color of a data point is set by the implementation used by this participant. One can observe that the participants with implementation 3 are all clustered with a low time and a low amount of two finger rotations, while all other groups are more randomly spread.

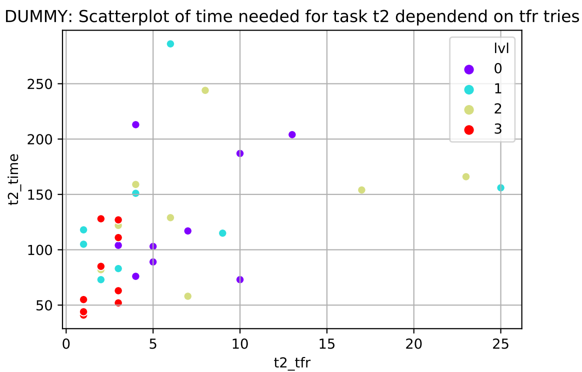


Figure 5: DUMMY: Time needed to fulfill the 2nd task for the toaster prototype depended on the number of tfr tries.

For the evaluation of the questionnaire, we calculated the SUS scores for every participant.

Figure 6 shows the scores mean for each case study group. The horizontal red line is at a score of 68, which in terms of SUS stands for average usability (see Foundations).

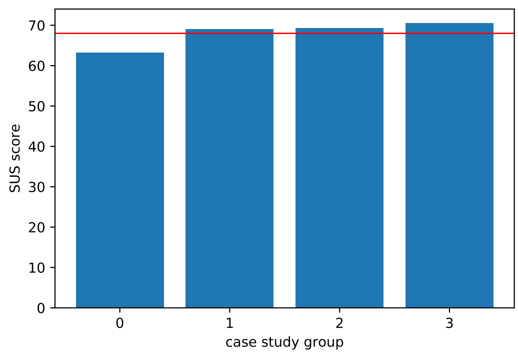


Figure 6: SUS score by the case study groups.

24 of the 40 participants answered the open question (*"If you have any suggestions on what kind of feedback from the app you would find better, please let us know"*). We categorize the answers with four different labels, divided by the topic the answer is about. These are *app feedback*, *app controls*, *prototype design* and *other*. Answers in the *app feedback* category are directed to the provided feedback messages or other desired feedback. Answers in the *app controls* category are about struggles with or improvement ideas for the applications controls. The *prototype* category is related to the prototype design and its usability, for example button sizes. The last category, *other*, is summing up single appearing answers which scope is not relevant for this research. The appearances of the different types of answers are listed in Figure 7. In case an answer fit to multiple labels, we count it for all the fitting categories.

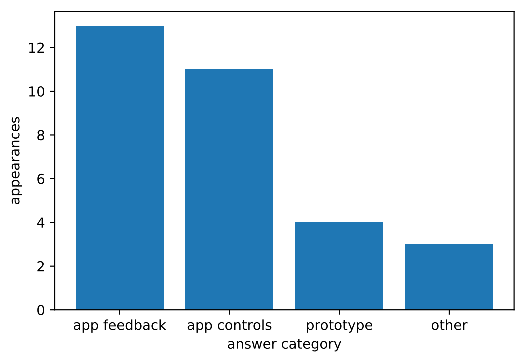


Figure 7: Categorized open question answers.

For a deeper evaluation of the answers we split them by the case study groups (see Figure 8). Most of the answers related to *app feedback* came from participants in the control group. All of this answers were asking for any kind of help. A lot directly asked for text messages providing help. Also the ideas of a help button or an introduction, which explains the controls were mentioned. Participants in the other groups also mentioned additional help implementation methods, like vibration feedback or help for the specific task from the application. Answers directed to our feedback message implementations were that they could be hidden by the fingers, when the user turns the phone and a participant with the *combined* feedback mentioned that the message should be visible for a longer duration. The other big category of the participants' answers is *app control* related. They have in common that the rotation of the piece of bread in the second task for the toaster prototype was not easy to archive for them. Also some were mentioning that the two finger rotation could be the more intuitive option.

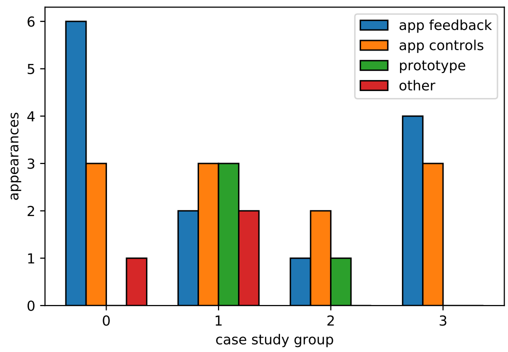


Figure 8: Appearances of answer categories by the participants case study groups.

Discussion of the Case Study Results

With the given setup of our case study the two finger rotation gesture appeared more often than the pinch zoom gesture (see figure 2). Usually, users attempt the pinch zoom gesture when an object on the screen is too small to see or use. Our participants started right in front of the object, so there was no need to step much closer to it. Also, for simplicity's sake, the prototypes were not created with unnecessary small controls, which means all of them were well visible in general. Clearly, there are other applications where users are more tempted to use this gesture. It is likely that outcomes of the evaluation of feedback messages for incorrect usages for rotation are applicable in a similar way for zoom and other functionalities. We have to divide the evaluation of the rotation into two groups, as we do for our *supportive* feedback implementation (see Approach). While most of the users intuitively walked around objects to rotate their view on the scene, they struggled more with rotating a certain object, namely a piece of bread in this case. This is the reason why the second task for the toaster prototype is most important. The specific task is just "Toast the bread", but this includes rotating the object laying on the plate (see 1 A) by 90° to put it into the device. The struggle with this task also becomes visible by the fact that only 10% of the participants were able to do it intuitively without trying a two finger rotation before. Therefore most users could profit from helpful feedback.

The feedback versions we provided performed differently in the case study. While the implementation with *critique* feedback and the implementation with *combined* feedback did not had a significant effect, the users with the *support* feedback were able to fulfill the task in less time and with significantly less attempts of the incorrect two finger rotation gestures. Prior knowledge about the usage of AR applications can not be a reason for it, because this groups participants had the lowest percentage of prior knowledge. Instead we can assume multiple reasons for this difference. One is that the *support* feedback implementation has a better visibility than the other two (see 1). While the other two implementations provide messages looking like the typical Android pop-up messages, the *support* feedback messages are larger and have a orange color instead of gray. Additional the messages of this implementation are shown for a longer duration. All this changes are there to make the messages more eye-catching for the users. This matches with our observation during the test that some of the participants with the *critique* or *combined* ignored the messages, which did not happen for participants with the *support* feedback. The other difference is the helpfulness of the messages' content. The *critique* feedback just tells the users what they have done incorrect, but not how they do it correctly. Since the actual rotation gesture was not intuitive for most participants, they could not come up with the right idea for rotation easily themselves. Our *combined* feedback implementation has a similar issue. The message popping for any kind of rotation is *"Rotating the object is not possible. Try moving around the object."*. This message does not provide the right help for the most challenging task, which is the rotation of the piece of bread, because it is designed for the wrong kind of rotation. The *support* feedback message serves better with *"Hold the object and move the phone to rotate"*, because its specific enough to help in the given situation.

Our data states that participants perform significantly better with the *support* feedback implementation, but we also asked the participants to assess their experience with our AR application themselves. Figure 6 shows that the average SUS result of participants in case study group 3 with the *support* implementation is only slightly higher then the others. So the impact on how the participants feel the usability is not as strong as the impact on how they actually perform. We asked the participants to assess the usability of the overall AR application, since that is what the feedback should serve to. Unfortunately other aspects have an impact on the general experience too. [So also the usability of the prototype itself was also rated by users], which makes sense because we tested the usability of our feedback with the use of the prototypes. That is why our case study groups are too small to evaluate the SUS results.

[a lot is missing here]

Summary and Outlook

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