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Exploring University Students' Preferences for Educational Robot Design by Means of a User-Centered Design Approach

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Abstract

User-centered design approaches have become more prominent in various domains and have slowly been adopted in robotics research. Previous research on user-centered design highlights the beneficial effects of actively involving end users into the design process. Results further imply that end users have different notions about ideal robot design, placing special demands on social robots depending on the context and personal factors. In the present exploratory research, we applied a user-centered design method and investigated university students' ($N = 116$) preferences regarding the design of educational robots. With regard to robot design, university students prefer a medium-sized machinelike robot with human characteristics and minimal facial features. Our results further suggest that a robot should primarily interact via speech and be able to display basic emotions, especially the positive ones. Additionally, from a university students' perspective, an ideal educational robot should display behavior that is marked by conscientiousness, agreeableness, and openness. We discuss implications of our results for educational robot design, and highlight the gains of user involvement in design decisions for human–robot interaction research.

Keywords Robot prototyping · User-centered design · Educational robots · User involvement

1 Introduction

A vast amount of research in HRI has documented the positive impact of using robots for education in different domains (e.g., enhanced learning, increased use of elaborated thinking skills, more collaborative interactions, etc.), with various robot types, and for different age groups [see 1, 2]. Nevertheless, different users may have distinct expectations and requirements regarding the physical appearance of educational robots as well as their application: While educational robots are predominantly preferred as teaching assistants, particularly in science, technology, engineering, and mathematics (STEM), or for learning processes in smaller groups [see 3–5], there is less of a consensus between students with regard to the appearance of educational robots. A recent study conducted with 24 interaction designers and 29 fifth-graders evaluated the preferred design of robotic teaching assistants [6]. It was found that interaction designers proposed smaller animal- or cartoonlike robots with facial features, while the children envisioned humanlike robots with clear robotic characteristics as teaching assistants. At the same time, though, these conceptualizations varied as a function of prior robot experience: Children with previous robot experience preferred smaller machinelike robots, whereas children without prior robot experience envisaged adult-sized humanlike robots with few mechanical features [6]. Further evidence for children's preferences for humanlike robots with mechanical features comes from [7], who found that fifth grade school students evaluated humanlike robots with obvious robotic properties most positively. On the other hand, work by Oros and colleagues [8] has suggested that first-grade elementary school students preferred animal-like robots with exaggerated facial features.

Taken together, the reviewed literature indicates that preferences clearly depend on both person- and context-specific factors. The existing body of research is sparse and to our knowledge, no previous study has investigated university students' design preferences for educational robots yet.

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However, university students represent a core end user group for educational robots. As common learning media (e.g., computers, smart boards, projectors, etc.) are applied both in schools and in universities, the application of robots in higher education can be reasonably assumed. More importantly, university education particularly strives for positioning novel computer technologies as fundamental educational resources [e.g., 9]. Therefore, university students' view is equally important and should not be ignored. To shed light on this user group, we conducted a study that utilized and validated user-centered design, a methodology that plays an increasingly important role in HRI research [10].

1.1 Robots for Education

In recent years, robots have entered educational environments and forecasts indicate that the trend will continue steadily [see 11]. Depending on the tasks they fulfil, different roles of robots in education arise [12]: First, an educational robot can function as a tool to teach and learn programming. Second, using a robot as a learning object concerns the actual creation and use of physical robots, for instance, in the field of mechatronics. Third, the robot as learning collaborator highlights a robot's role "as an all-season companion, aide, and even intellectual foil" [12]. Indeed, this latter role of educational robots is in the focus of the present work. We aimed at designing a robot that can serve as a personal learning companion that, for instance, helps students to edit tasks, promotes the individual learning process, provides information on specific topics, or gives feedback on students' progress. Such a robot should be applicable across all disciplines and for all student groups. Nevertheless, it remains important to consider that context- and person-specific factors might influence students' preferences for educational robots. In our study, we therefore sought to investigate university students' preferences for educational robot design which have not been investigated yet.

2 Theoretical Background

2.1 User-Centered Design

User-centered design seeks to actively involve different stakeholders in design processes in order "to gain access to the experiencer's world only through his or her participation in expressing that experience" [13, p. 90]. There is no clear-cut definition of user-centered design, especially as it is tightly connected to collaborative design, co-creation or co-design practices (where users likewise become central to the design process), and terms are often used interchangeably [see 14, 15]. User-centered design is an iterative methodology that prompts researchers and designers as well as end users to co-interpret an emerging design in the ongoing process [e.g., 16]. This implies that user-centered design is a reciprocal process. On the one hand, users play an important role in knowledge development and idea generation. On the other hand, researchers provide tools for ideas and expression, and the designers finally shape the ideas [15]. Consequently, user-centered design fosters mutual exchange in order to create usable products, tools, systems, interfaces, or software programs, for instance, that meet the needs of end users. User-centered design activities bring positive outcomes to both companies and users as these methods consider end users' needs and thereby increase consumers' willingness to use and purchase a product [e.g., 17–19]. From a psychological perspective, findings suggest that users ascribe a higher subjective value to a product when they actively participated in the design process [20].

2.2 The Emerging Role of User-Centered Design in HRI

User-centered design has become an important approach for researchers from different domains such as computer-supported cooperative work, architecture, marketing, or human–computer interaction [see 16]. Currently, user-centered design is becoming increasingly vital in HRI research [e.g., 21–24]. However, so far, many HRI researchers have utilized methods to design robots that primarily aimed at meeting user requirements by passively observing and evaluating HRI [19]. A vast amount of laboratory and field studies have been conducted to provide insights into users' design ideas [e.g., 25–29]. More recent user-centered design approaches have involved end users in the process more directly by investigating and evaluating their attitudes and perceptions regarding existing robots [e.g., 21, 30–32]. Notwithstanding, in these works, participants still maintained a relatively passive role. They merely evaluated the design of a product that researchers have envisioned and developed for a certain purpose or task.

User-centered design in HRI, however, should allow for the exploration of a more reliable perspective of users' needs. User-centered design actively involves users in design processes and changes participants' roles from modifying existing robot design to developing new robots [23]. Recent studies have confirmed this insight: For instance, Šabanović and colleagues [22] have developed design concepts for socially assistive robots by involving seniors diagnosed with depression and their care staff in the design process. To do so, participants took part in two participatory design workshops. In the workshops, they learned about existing assistive robots (e.g., PARO, Care-O-Bot, Papero) and then cooperated with the researchers to design assistive robots that would fit ideally into their everyday lives. Findings indicated that both older adults and care staff were interested in the introduction of socially assistive robots into therapeutic services and willingly participated in the participatory design project. With respect to robot design, seniors mentioned that an assistive robot should be humanlike in size and appearance, easy to handle, while also being portable to accompany them in daily activities (e.g., taking a walk in the park, visiting the doctor, etc.). In a follow-up study with another sample of seniors [23], participatory design workshops were conducted once again and included, for instance, an introduction to existing robot technologies, co-design of a robot for daily live use, and a presentation and testing of different robotic sensors. As a result, the researchers have emphasized the importance of including users into design processes: This allows to draw on their rich experience and to meet their needs while also considering their relation to other persons and institutions. Furthermore, similar to the first study [23], participants preferred a humanlike appearance and a robot that would provide companionship in everyday life.

Besides co-designing assistive robots for everyday life, user-centered design methods to build robots for learning purposes are gradually gaining importance: To illustrate, Obaid and colleagues [6] have implemented user-centered design by applying a creative drawing approach. First, they instructed elementary school children to express their ideas and to discuss them in a group. Second, the children were asked to draw a teaching assistant robot. The results indicated that children preferred a humanlike robot with clear robotic features like a screen, sensors, or robotic hands to carry tools in the classroom. In a follow-up study, the authors developed and evaluated a robot design toolkit [33]. For this purpose, the initial drawings were analyzed with respect to different robot features, and 3D-printed body parts (e.g., heads, torsos, legs, arms, and materials) were created. To evaluate the toolkit, 31 school children were asked to construct a classroom robot using the different elements. After the building phase, children had to write a story about the robot's behavior in the classroom in order to get additional information on children's imagination about further robotic characteristics. The results confirmed the findings of the previous study [6]: Children preferred a rather humanlike appearance with robotic characteristics like a metallic surface or mechanical arms. Children further added that the robot should have a screen on the torso, a storage compartment for school materials, and a button to turn off the robot.

In sum, the existing body of research suggests that user-centered design is well suited for advancing robot development and for increasing user acceptance of novel platforms. This design approach provides valuable insights into end users' concepts of how to integrate robots in their daily lives and accordingly, how to design robots for their purposes. Yet, there is still a need to resolve pending issues regarding the ideal educational robot design: For instance, educational robot designs for different learning contexts (e.g., schools, universities), and according to different personal factors (e.g., age, gender, personality) as these factors have not been sufficiently investigated so far. More precisely, university students have gained profound learning experiences and have developed individual learning style preferences, while younger school children have to mature their learning skills and learn how to handle educational media. Consequently, it can be expected that these two groups have different needs in terms of using learning media. The present work contributes to our understanding of how to design novel educational technologies, namely educational robots, in the context of university education, with a particular focus on undergraduates' expectations. The present exploratory study thus seeks to investigate which external robot design and which robot capabilities (e.g., interaction, personality, emotion) university students envision as optimal for educational robots.

3 Methods

3.1 Participants and Procedure

Participants in the present online study were 116 (74 females, 39 males, three persons did not indicate gender) university students aged between 17 and 40 years ($M_{age}=23.29$, $SD_{age}=4.05$). $N=57$ studied in fields related to science, technology, engineering, and mathematics, whereas $n=57$ studied social sciences and humanities, (e.g., psychology, education, etc.); two respondents did not report their major. The online study was run using the software Unipark (QuestBack GmbH, Cologne) and data collection took place between February and March 2017. Respondents were recruited via electronic bulletin boards and social networking services. The completion of the survey took approximately 15–20 min. At the end of the survey, participants were debriefed and could subscribe for participation in a raffle to win a voucher worth € 30.

3.2 Design Process and Stimuli

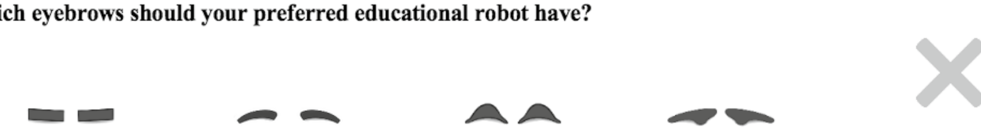
In the present work, we focused on visual prototyping of an educational robot as we pursued the objective of involving users as efficiently and simply as possible in the first stages of a design process. Thereby, we benefitted from the advantages of prototyping: Active user involvement, rapid design, creation with less effort, or early identification of problems in the design process, for instance [34].

To realize the design process, we combined various user-centered design models that have previously been applied in different fields [e.g., 35–37]. Mainly inspired by the *Collaborative Design Model* by [37], an effective and user-specific design process, we implemented the following phases in our design process of an educational robot (see Table 1 for a summary of the five steps): In the planning phase of our study, we first searched for images of different existing robot platforms via Google Image Search using the term ‘robot’. Previous work pointed out that “even when a new design is created, it arises from existing genera rather than being totally new” [35, p. 252]. Based on this assumption, we preselected 30 robot images of different robot platforms, for example, Asimo (Honda), NAO, Pepper, Romeo (SoftBank Robotics), MiP (WowWee Robotics) or RIBA (RIKEN), to have an extensive base of different robot types and shapes. We applied the following criteria for selecting the images of the robot platforms: First, the image had to depict the whole robot. Second, we only selected robot platforms that are on the market or used in research. Third, we only included social robots, for instance, robots that are capable of interacting and communicating with humans (e.g., physically embodied, head/screen to represent a head/face). In the second phase, we evaluated the images and selected the most common shapes of different robot parts (e.g., round, oval, rectangular head/torso, legs, wheeled base, etc.). Subsequently, in a third step, we prepared standardized drawings of the different robot parts (see Table 2 for example drawings). In phase four, we developed an online questionnaire depicting the different robot parts and asked for students’ preferences regarding each specific characteristic (see Sect. 3.3 for a detailed description of the eligible robot characteristics). In the final phase, we evaluated the most frequently selected parts and prepared a visual prototype of the ideal educational robot based on university students’ view.

Table 1 Overview of the user-centered design process

Phases	Description
Phase 1	Search for images of different robot platforms
Phase 2	Selection of different robot parts and features
Phase 3	Preparation of standardized drawings
Phase 4	Students’ selection of the preferred robot features
Phase 5	Visual prototype of the robot

Table 2 Example items for the eligible robot characteristics used in the online questionnaire

Characteristic	Example Item
Appearance	**Which head shape should your preferred educational robot have?** 
	How should your preferred educational robot grasp or touch things? 
	Which eyebrows should your preferred educational robot have? 
Interaction	**How should your preferred educational robot interact?** (multiple responses were possible) Speech, Touchscreen, Facial expressions, Gestures, Touch, In written form
Personality	**Which personality traits should your preferred educational robot have?** (multiple responses were possible) Conscientiousness, Openness, Extraversion, Agreeableness, Neuroticism
Emotion	**Which emotions should your preferred educational robot display?** (multiple responses were possible) Happiness, Sadness, Fear, Surprise, Disgust, Anger

3.3 Robot Characteristics

People still do not have a clear idea about the functions and capabilities of robots as the majority of people is not familiar with robots, at least not in the European context [38]. To give participants a general idea, we provided them with a short, written introduction to the features and functions of educational robots and focused the introduction on the role of educational robots as learning collaborators [see 12]. We deliberately avoided using images of already existing educational robots and other social robots to circumvent biasing participants' responses in the subsequent design task. Participants read the following introduction to educational robots:

Educational robots can be used as assistants to teachers and can help to arrange lessons. Further, educational robots can serve as personal tutors that help students to edit tasks or to promote their individual learning process. Educational robots can assist in the following areas: They can, for example, provide information on specific topics, query learned lessons, give advice to the learning process, correct errors, or provide feedback on students' progress.

Afterwards, respondents had to indicate their preferred educational robot design by choosing between different features. Based on findings by [7], the implemented items comprised the aspects *appearance*, *interaction*, *personality*, and *emotion*.

3.3.1 Appearance

As the first item that assessed overall appearance, participants could choose between a rather humanlike, animal-like or machinelike appearance. The items that followed were adjusted correspondingly (e.g., animal-like features like a beak, muzzle, paws, etc. were presented if participants selected an overall animal-like appearance; analogously, legs, hands, hair, etc. were provided as options if participants selected a humanlike appearance). Afterwards, participants could choose the preferred gender, size, head shape, torso, base, arms, hands, colors, and facial features for their ideal educational robot. Table 2 depicts example items for the different choice options.

3.3.2 Interaction

We first asked participants whether an ideal educational robot should be able to distinguish between different persons. To indicate the favored way of communicating with an educational robot, students could choose from the following options: speech, touch screen, facial expressions, gestures, touch, or information in written form (e.g., using an interface).

3.3.3 Personality

With respect to personality, we first asked participants to indicate whether an educational robot should identify and adapt to human personality traits. If participants responded positively, we requested whether students favored specific personality traits for an educational robot, and asked them to indicate their preferences for robot personality using the Big Five personality traits: conscientiousness, openness, extraversion, agreeableness, and neuroticism [39]. To ensure that people who were not familiar with these personality traits understood the traits properly, we provided participants with example items for each trait (e.g., for agreeableness: sociable, trustful; for neuroticism: fearful, restrained; or for openness: imaginative, creative).

3.3.4 Emotion

We asked participants whether their ideal educational robot should recognize people's emotions, whether it should express emotions, and if so, which emotions it should display. Participants could choose from the six basic emotions: happiness, anger, fear, surprise, disgust, and sadness [40].

4 Results

To examine which external design and capabilities (e.g., interaction, personality, emotion) university students generally envisage for their ideal educational robot, we focused on the most frequently reported preferences. For this purpose, statistical analyses were performed using IBM SPSS 21 for Windows (SPSS Inc. IBM, Chicago). We counted frequencies of participants' choices. For questions with single response, the percentages of the individual answers add up to 100%. In the case of questions with multiple answers, the percentage of respondents who have chosen the respective answer is provided.

4.1 Appearance

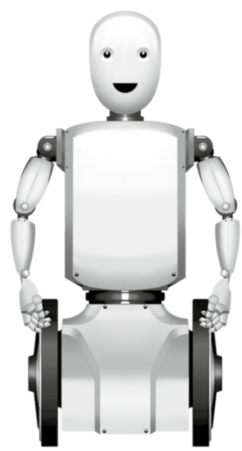
With respect to university students' desired appearance for educational robots, nearly half of the students preferred a machinelike robot (54.3%) over a humanlike (38.8%) and an animal-like robot (6.9%). The robot should be gender-neutral (75.0%), instead of having a male (14.7%) or a female gender (10.3%). Further, students favored a medium-sized robot (~ 100 cm; 75.8%) over a small (≤ 50 cm; 11.2%) and a big robot (> 150 cm; 12.9%). Table 3 illustrates students' preferences for the single body parts. Regarding preferred colors for an educational robot, students indicated that they would preferably use neutral colors like white (71.4%), grey (48.2%), and black (44.6%). Blue (26.8%) and green (21.4%)

Table 3 Percentages of valid answers for preferred body parts

Body part	Percentages of valid answers (%)
Oval head	30.2
Rectangular body	42.2
Wheeled base	53.4
Two arms	75.0
Hand with five fingers	48.2
Round eyes	34.5
Semicircular mouth	51.7
No nose	50.9
No ears	26.7
No hair	80.4

The presented body parts reached the highest scores among all options for each category

Fig. 1 Image of the preferred educational robot prototype



were favored over colors such as red, orange, yellow, turquoise, or purple (< 12%). Figure 1 depicts the desired prototype according to university students.

4.2 Interaction

80.4% of the students stated that the robot should distinguish between different persons (e.g., recognize human faces, use people's names). Interestingly, nearly 20% favored the robot not to distinguish humans (17.9%; 1.8% had no opinion). With respect to the robots' interaction mode, Table 4 displays university students' preferences.

4.3 Emotion

A major part of the respondents indicated that their ideal educational robot should recognize human emotions (71.4%), whereas 19.6% disagreed with this. A small portion of students (8.9%) had no opinion on this issue. Around half of the students (55.4%) stated that the robot should express emotions itself. More than one quarter of our participants rejected the idea of robots displaying emotions (28.6%), while 16.1% of them were undecided. Table 5 presents the emotions that an educational robot should preferably display.

Table 4 Percentages of valid answers for preferred interaction mode for HRI with an ideal educational robot

Interaction mode	Percentages of valid answers (%)
Speech	98.3
Touch screen	65.5
Touch	63.8
Gestures	56.9
Facial expressions	47.4
Information in written form (e.g., interface)	33.6

Table 5 Percentages of valid answers for preferred emotion display of an ideal educational robot

Emotion	Percentages of valid answers (%)
Happiness	92.2
Surprise	86.2
Sadness	41.4
Fear	25.9
Anger	25.9
Disgust	18.1

4.4 Further Characteristics

Finally, we administered an open question to explore which additional characteristics and features students' ideal educational robot should have. A qualitative content analysis of the open-ended question was conducted by two independent raters. We measured the agreement between the two raters by calculating interrater reliabilities (Cohen's κ). Our findings revealed the following expectations: First, students endorsed the robot's ability to motivate and to adapt to individual learners. The second aspect concerned the robot's physical traits: Respondents mentioned that an educational robot should not look and behave too humanlike. Third, students highlighted privacy and safety aspects. They emphasized that the robot should not be harmful and always be possible to turn off. Fourth, students appreciated easy handling. Finally, students did not appreciate negative personality characteristics: For instance, an educational robot should not be pessimistic, annoying, boring, or demotivating from university students' view. The agreement between the two raters for the categories was found to be good, $\kappa = .74$, (95% CI, .536–.917), $p < .001$).

5 Discussion

New technologies like computers, tablets, or online learning programs are not only standard equipment in learning and teaching practices in contemporary schools, universities and other educational institutions, they are also adaptable to persons and contexts so as to accommodate different learning constellations and environments. With respect to human–robot learning, the introduction of robots into learning settings and their adaption to specific learning situations is in its infancy, especially with respect to robot design. Although the number of different robot platforms for learning purposes is growing steadily (e.g., NAO, Home Education Robot, Engkey), only few design approaches have actively involved students and have considered their expectations and expertise [e.g., 6, 33]. Additionally, previous research has documented that designers and students envision very different designs, stressing the diverging views of designers and potential end users [6]. Clearly, there is a need to consider university students as a key target group, particularly because we still need to explore in more depth their concepts and expectations of educational robots. The present exploratory work therefore investigated university students' design preferences for educational robots by drawing upon the practice of user-centered design. As a result, our findings have the following significant theoretical and practical implications for educational robot design:

5.1 Appearance

We found that university students preferred a machine-like robot with human features (e.g., oval head, hands, facial features). This result partly corresponds to school children's perceptions, who envisioned a relative human-like robot with apparent robotic characteristics [e.g., 6, 7, 33]. With respect to gender, students stated that the robot should preferably be gender-neutral. It seems possible that gender does not play an important role for educational robots. If so, this could be exploited to reduce persisting gender stereotypes in education. Relatedly, previous work has suggested that robot gender does not significantly affect students learning and motivation [see 41]. In the present research, participants further indicated that in their view, an ideal educational robot should be approximately 100–150 cm tall. This size allows students to be on eye level with the robot when sitting at the table and learning together. Interestingly, university students preferred a wheeled base for locomotion. Plausibly, this would contribute to smoother navigation [42]. With respect to facial features, we found that the robot should have only eyes and a mouth. Regarding colors, university students' perceptions differ from school children's expectations: Adults prefer less colorful robots and more neutral colors.

Taken together, our findings regarding the ideal appearance of an educational robot revealed that compared to school children, university students imagined a rather machinelike robot design; they particularly appreciate a functional and simple design. Precisely, for human–robot learning in university contexts, robot developers should therefore focus on building medium-sized robots in neutral colors with a wheeled base, arms, hands, eyes, and a mouth.

5.2 Interaction

The majority of respondents stated that an educational robot should distinguish between different persons. This result further supports the idea that robots should be capable of differentiating between learners and of monitoring their individual learning gains in order to provide individually tailored support [see 43]. Accordingly, students in our sample mentioned that an ideal educational robot should adapt to them and apply appropriate learning methods for each learner. Surprisingly, however, nearly 20% of participants rejected this feature. It may be that these students feared being constantly monitored and controlled. Another important finding concerned the fact that almost all participants preferred to interact with the robot via speech, which is probably the easiest and most natural interaction mode for humans. This underlines the fact that work on efficient speech recognition and speech output has to be continued. Nevertheless, the robot should also be equipped with a tablet (like the Pepper robot by SoftBank Robotics) to help students gather information or illustrate explanations. This observation supports previous findings by Ray and colleagues [44], who found that people prefer to interact verbally with a robot, followed by interaction via touch screen. In general, as educational robots are especially intended to interact with students, natural and smooth interaction is of great importance in this context and provides a framework for further challenging design issues (e.g., robot voice, sound source localization, etc.).

5.3 Personality

In the present study, only half of the students indicated that an ideal educational robot should adapt to a learner's personality. Nevertheless, students significantly preferred the robot to behave conscientiously, agreeably, and openly. Interestingly, we found that only about one third of the university students favored an extraverted robot personality—a finding that is contrary to previous studies which have suggested that people particularly prefer an extrovert robot personality for HRI [e.g., 45–47]. However, when considering conditions for successful learning, the personality traits conscientiousness, agreeableness, and openness seem well comprehensible as they can help to facilitate the interaction between learners. This assumption is also supported by findings showing that the Big Five traits conscientiousness, agreeableness, and openness are positively related to different learning styles and successful learning strategies [e.g., 48, 49]. With respect to neuroticism, prior research highlighted the negative link between neuroticism, effective learning styles, and academic achievement [e.g., 48, 50]. Thus, it is not unexpected that students rejected a neurotic robot personality.

5.4 Emotion

Prior work on robot design observed the importance of robotic emotion display among children [e.g., 8, 51, 52]. In contrast to these findings, our results suggest that although most of the students expected the robot to recognize human emotions, only half of them wanted an educational robot to actually be able to do so. Additionally, respondents preferred the robot to express positive emotions (e.g., happiness, surprise), but not negative ones (e.g., anger, disgust). This finding is not surprising as negative emotions reduce motivation and hinder learning [53], while positive emotions promote well-being [54] and motivation [53], facilitate learning strategies, and overall positively affect learning performance [53]. Besides, this assumption concurs with our finding that the robot should have minimal facial features that allow the robot to show only basic positive emotions.

In sum, while emotional responses seem to be rather important for children, young adults focus less on a robot's emotional capabilities. Thus, robot design for university education should rather focus on implementing useful positive emotional feedback instead of offering a broad spectrum of emotional responses. Nevertheless, facial expressions can be easily understood by humans and reflect an important response mechanism [e.g., 29, 55] confirming their importance for HRI.

5.5 Further Characteristics

Consistent with our quantitative data, the qualitative content analysis of the open-ended question demonstrated that university students do not prefer a too humanlike educational robot. Students envisage rather a machinelike robot that should have limited human characteristics, especially with respect to its physical appearance. Further, an ideal educational robot should be easy to handle to prevent interruptions during learning processes. Similar to findings by [21] and [33], participants reported the need to maintain control over the robot. The robot should not be harmful and should readily be shut off at any time. It seems that students fear a loss of privacy or security when they are surrounded by an autonomous robot. This is not surprising, when we keep in mind that robots are usually able to sense, record, and process their environment. Thus, when designing robots, it should be clearly recognizable when a robot's sensors are activated or deactivated to reduce people's feeling of constant surveillance. Besides, an easily accessible power button contributes preventing injury to persons and damage to the robot, and gives humans a sense of security and control. This is an important issue for future robot design and HRI research that offers abundant material for discussion from an ethical perspective [see 56, 57].

5.6 Lessons Learned

Taking an applied perspective, we have shown that robot design for educational purposes in the university context should focus on developing simple and useful robot platforms. Based on our findings, we therefore recommend a rather machinelike robot appearance with human characteristics: A wheeled base, for instance, contributes to smooth navigation, a touch screen offers the opportunity to visualize learning contents, while a head, facial features, or hands give the robot a humanlike appearance. We further propose to keep the design gender-neutral and to implement minimal facial features as numerous features (e.g., nose, hair) could contribute to uncanniness and might distract people from learning. With respect to actual HRI, the obtained results suggest that educational robots should be equipped with clearly understandable speech output as speech is the most natural form of interaction for humans.

From a theoretical viewpoint, our study provides further evidence for the negative link between negative emotions and successful learning: A negative mood and anxiety exert negative effects on learning and performance [e.g., 58, 59]—and can thus negatively affect human–robot learning as well. Further, with respect to the educational perspective, the obtained results enhance our understanding about the type of personality traits in robots which are deemed relevant for successful HRI in educational contexts (e.g., conscientiousness, agreeableness). Our findings thus provide empirical evidence as a basis for actual HRI studies which investigate how a conscientious or agreeable robot personality would affect students' learning. It remains a difficult research question in and of itself, however, how to build a conscientious and agreeable robot personality [see 60].

6 Future Work

Although the current study offered insights into university students' preferences for educational robot design, we have to acknowledge that we provided participants a rather broad definition of an educational robot's characteristics. This probably contributed to different perceptions and expectations on the part of the students. Future work could usefully explore whether a clearer and more precise definition of the features, functions, possibilities, and limitations of educational robots would produce divergent results regarding students' requirements for educational robot design.

Even though a relatively large number of participants ($N = 116$) took part in the present research, the generalizability of our findings is still limited. In fact, students' preferences for robot design may vary depending on students' age, educational setting, learning domain, or cultural factors. Thus, future work needs to examine more in depth which of these other factors might affect preferences for robot design. Further, although we were interested in examining an ideal robot that could foster learning independent of a particular field of study—a process that can be deemed similar across all disciplines—we want to point out that future research should take students' educational background into consideration.

Additionally, we have to acknowledge that our implementation of user-centered design lacked a direct exchange and interaction between students and researchers. While one great strength of our study lies in the fact that we asked for university students' design preferences without biasing their perception by giving too much information on social robots, one idea of user-centered design, namely the researcher as a facilitator who brings in background knowledge to guide people's expressions [15], has not been addressed sufficiently. In terms of directions for future research, it is therefore recommendable to strike a balance between directly guiding end users' participation in design efforts and not influencing users' design decisions to a great extent. However, future work should involve users in all phases of the design process: First, we recommend involving users right at the beginning into the analysis of requirements related to the application of robots in education. Users should be provided with a clear definition of what an educational robot is, and in which areas it can serve to promote learning. In the second step, the design of the robot, researchers should provide users with useful tools to express themselves, while users should have the opportunity to express additional needs with respect to the robot's functions and characteristics. In the third step, users should have the opportunity to evaluate the resulted prototype with respect to its applicability and usefulness. Finally, we suggest to involve users in the final step, namely the implementation of the robot into learning settings. In this context, users can express their ideas and concerns regarding a smooth integration of educational robots.

Finally, further work needs to be done to evaluate our prototype by future end users, namely university students, and decide whether a re-design is necessary based on students' feedback. Such an evaluation study could provide, for instance, insights on users' perception of the external design, their expectations regarding the robots' usability for learning, and students' willingness to apply the robot for their learning.

7 Conclusion

The present research was the first to investigate university students' preferences for educational robot design and one of the few studies in HRI that have realized a user-centered design approach with real potential end-users. Overall, our study emphasizes the importance of involving different end users in design processes of social robots. That is, we clearly demonstrated that university students' design requirements do not correspond with younger school children's concepts about robot appearance and functionalities as found in prior work [e.g., 6–8]. Young adults tended to focus on the value of functionality or safety of robot design, for instance, while school children have put more emphasis on a robots' expressiveness and friendly appearance. Above and beyond the robots' external appearance, we further established that university students have a precise idea in mind regarding how an educational robot should interact or how it should behave. Summing up, the present research documents the importance of a cooperative design approach, which can be realized optimally by means of user-centered design.

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Compliance with Ethical Standards

Conflict of interest The authors do not have any interests that might be interpreted as influencing the research. The authors declare that they have no conflict of interest.

Ethical Standard Our research is approved by the ethics committee of Bielefeld University (approval ID: 2016 – 173). We report how we determined our sample size, all data exclusions (if any), all manipulations, and all measures in the study.

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