A Study on The Adoption of Virtual Reality in Industrial Design Education

Ahmet Hamurcu, Şebnem Timur, and Kerem Rızvanoğlu

***Abstract*—Virtual reality (VR) technology has been commercially and economically accessible to industrial designers for the past seven years, following the introduction of VR glasses and headsets, e.g., the HTC Vive and the Oculus Rift, in 2016. However, despite the growing popularity of VR implementations in education, it remains unclear to what extent industrial design (ID) students and instructors will adopt this technology. Hence, this paper discusses the limited adoption of VR technology in ID education based on the analysis of qualitative data obtained from ID students and instructors, specifically their perspectives on integrating VR into the education process. The data set comprises written and verbal expressions obtained through an online form and a group discussion session. The findings obtained from the analysis conducted through the content analysis approach suggest that both ID students and instructors harbor concerns regarding the incorporation of VR technology in ID education. These reservations primarily revolve around the potential adverse impacts of VR usage on students' skill development in terms of manual dexterity and material knowledge, as well as the effectiveness of its implementation within the context of ID education.**

***Index Terms*— Industrial Design Education, Learning Environments, Learning Technologies, Virtual Reality.**

I. Introduction

VIRTUAL reality (VR) technology supports and supplements traditional education by creating immersive and interactive environments that enhance teaching and learning processes [1], [2]. Therefore, as VR equipment becomes more affordable, its popularity in education is rapidly increasing. Accordingly, there is a notable surge in academic research dedicated to exploring the educational applications of VR. Recent literature reviews [3] and [4] focused on the use of VR in education reveal a substantial rise in the number of articles published in peer-reviewed journals indexed by Web of Science and/or Scopus, especially from 2016 onwards. According to [3], which covers a broader period and encompasses a larger quantity of articles, the number of publications (4904+) during the six years leading up to 2023 is more than three times the number of articles (1517) published in the previous 25 years, spanning from 1992 to 2016. It can be said that there are two reasons behind this massive increase:

1) The advancement of VR technology in the mid-2010s, including the introduction of the Oculus Rift in 2014 [4], and the accessibility of reasonably priced VR headsets, e.g., the HTC Vive and the Oculus Rift, for educators, students, and educational institutions, beginning in 2016 [5];

2) The acceleration of digitalization in education resulting from the COVID-19 pandemic [4].

In the last six years, when the number of studies has significantly increased, researchers have conducted studies on a wide variety of topics, ranging from preschool to higher education, covering all levels and types of education. The topics most commonly covered in studies during this period can be listed by giving the references of one or more examples as follows: how VR can be utilized in education [6]–[9], teaching and/or learning processes using VR [10], [11], VR learning environments / VR platforms for education [12]–[14], the effects of VR use in education [15]–[17], the effectiveness of VR use in education [18]–[22], the application of VR in other knowledge fields related to education [23].

According to Rojas-Sánchez et al. [4], these studies also reveal that despite VR technology being available for many years and receiving significant attention from the new generation of students, educational institutions have not adopted it as quickly as anticipated. A similar situation has been observed in ID education.

ID education is primarily founded on the evaluation of design ideas through communication between students and instructors within a studio setting. This communication in ID education, referred to as design communication, relies on the externalization of these ideas, particularly by utilizing visual tools and/or techniques [24]. Making design ideas visible paves the way for dialogue between students and instructors, with design knowledge and ideas being transmitted and communicated between these two parties through this dialogue [25], [26]. All teaching and learning processes and mechanisms within ID education based on this dialogue [27]. Due to its significance, the visualization of design ideas is a requirement for ID students [24]. As a result of its importance, students are often highly motivated to employ computer-based technologies for creating these visualizations. Consequently, computer-based technologies for design visualization, such as

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computer-aided drawing/design (CAD) and digitizing tablets, were rapidly embraced, and this situation was described by Dorta et al. [28, p. 164] as "premature introduction of" and traumatic transition to computerization for ID studio course environments.

On the other hand, in 2016, with the release of VR headsets, e.g., the HTC Vive and the Oculus Rift, coupled with appropriate software, new computer-based technology became economically accessible in the field of ID. This novel technology offers several valuable advantages to ID processes and education. These advantages include enhancing the visualization of design concepts, which is fundamental to ID; facilitating iterative design processes by providing a platform for quick and cost-effective prototyping; ensuring that designs are user-centered from the outset, enabling us to simulate user experiences and gain valuable insights into human factors; and promoting collaboration with peers and other stakeholders of a project from different parts of the world [29]. Moreover, the interactive nature of VR aligns well with the active learning methodologies in design education [30]. Furthermore, the COVID-19 pandemic accelerated the adoption of online and hybrid learning models. Concerning this issue, VR can bridge the gap between face-to-face and distance education by providing a more engaging online design education experience [31]. Additionally, the evolution of VR hardware has made VR accessible and practical for educational purposes. For example, high-resolution headsets have significantly improved visual fidelity, reducing the "screen door effect" and enhancing the sense of immersion, while lightweight and wireless VR headsets, like the Oculus Quest series, have increased mobility and comfort, making them suitable for long training sessions [32]. However, despite all these substantial advantages for ID and its education, it remains uncertain whether this immersive technology, enabling users to experience computer-generated visualizations as if they were real, will be widely adopted in ID education, particularly in developing countries. For this reason, this paper discusses the reasons why this type of VR technology has not yet achieved widespread adoption in the field of ID education, based on insights from both ID students and instructors. This discussion is grounded in a reanalysis of a data set obtained from a previous study [33].

II. Background

Davis [34] suggests that if individuals believe technology can enhance their work efficiency and effectiveness, they are more likely to adopt that technology. Therefore, in order to discuss the future of VR in ID education, it should first be addressed why and how currently adopted computer technologies are utilized in ID practice.

According to Hamurcu *et al.* [5], before the advent of computer-based technologies, making design ideas visible required students to either draw and/or render on paper or craft physical models or prototypes. However, these methods, relying on manual skills, were dependent on the personal abilities and efforts of students. In the early 1980s, as personal computers and CAD software became economically accessible for designers [35], [36], drawing, rendering, and modeling transitioned into digital practices, offering greater precision and ease. Thus, computer graphics emerged as digital alternatives for these fundamental activities in the creation of design representations, and their use has become widespread, particularly with the increasing portability of computers.

In the 1990s, pen-based interaction devices emerged commercially. These devices, initially used as computer peripherals, enabled designers to draw and render using natural hand motions directly and digitally. This technology introduced a new form of human-computer interaction, distinct from the keyboard and mouse combination. By this means, even computer screens became usable as if one were working on a paper surface [37].

On the other hand, with the integration of computer technology into machining tools, the three-dimensional (3D) design representations created in computer environments became physically producible by sending them to computer numerical control (CNC) machining tools, such as laser cutting, milling, waterjet cutting, and 3D printers. In other words, the production of accurate physical models or prototypes became faster and easier for designers [5].

Over time, these technological advancements have solidified the position of computer-based technologies as tools frequently used not only by professional designers but also by ID students. However, these technologies primarily offered digital alternatives for creating design representations and did not bring about a significantly remarkable innovation in the presentation of design ideas. As mentioned earlier, before the emergence of these computer technologies, designers had two main options depending on manual work: drawing and rendering on paper; and/or crafting a physical model or prototype. However, drawing and rendering on paper comprise an effort to illustrate 3D design ideas on a 2D surface, while making a physical model or prototype contains struggling with challenges, such as material limitations. In other words, before computerization, a designer was confined either to the 2D realm of paper when trying to create a design representation through drawing and rendering or had to overcome material-related problems when attempting to craft a physical 3D representation. CAD technology empowered designers to generate 3D design representations without the need for any physical materials. In this way, during the creation of these 3D representations, they got rid of the constraints imposed by 2D paper surfaces and material-related complications. On the other hand, for presenting the representations generated within computerized environments, designers still have to print them on paper or display them on a digital screen or project them onto a surface. However, papers, digital displays, and projection screens inherently exist as 2D planes. In this case, it cannot be said that the constraints mentioned above have been eradicated [5].

In the mid-2010s, VR environments, where viewers can interact naturally and intuitively with digital representations, became economically accessible to designers with the release of VR headsets and related software. This marked a new era in computer technology for designers, not only offering an alternative method for creating design representations but also introducing an entirely new way of presenting, evaluating, and experiencing them. Due to these capabilities, it was swiftly adopted by professional designers in various industries, including automotive, furniture, and consumer durables [5].

On the other hand, designing also involves an iterative and creative procedure. As stated in [38], the ID process constitutes a subset of the (new) product development process, separate from manufacturing processes. Similarly, according to the "Double Diamond" model by the Design Council [39], the ID process comprises four successive phases: "Discover," "Define," "Develop," and "Deliver." This model culminates in choosing a feasible solution, ready for subsequent manufacturing procedures. Likewise, the widely recognized "Delft Design Guide" [40], concludes the ID process by elucidating and simulating design proposals, omitting the manufacturing processes.

From a different perspective, Cross [41] defines the "designer's area" as between “ill-defined problem” and “well-defined solution”. Following this notion, it can be said that designing initiates with an idea triggered by a specified problem. According to Audi's interpretation [42], an "idea" is a mental depiction, rendering it virtual. Consequently, designing can be seen as originating from a virtual idea. Additionally, according to the stages proposed by the Design Council and Delft Design Guide for the ID process, the "Define" phase, succeeding the "Discover" phase, is the second stage where the problem is outlined. Hence, an additional sub-process of the ID process begins after the "Define" phase, which can be termed the "act of designing" process. Pei [43, p. 127] defines the "act of design[ing]" as envisioning and subsequently processing mental images. Self et al. [44] delineate it as a practice encompassing three general phases: concept design, development design, and detail design. Conversely, Galle [45] associates the boundaries of the design process with the creation of design representations. He elucidates "designing itself as the production of a design representation" [45, p. 58]. Therefore, it becomes evident that the various design representations categorized in Pei et al.'s study [46] emerge within these three aforementioned general stages. Consequently, the act of designing, originating from a virtual idea, advances toward a tangible product through the design representations crafted during the concept design, development design, and detail design phases. Nonetheless, this progression halts just before realization, at the point nearest to reality. As a result, its outcomes manifest as immensely lifelike representations, in other words, "virtually real" representations.

To summarize, designing can be characterized as an endeavor to portray a nonexistent product as though it already exists. In contrast, VR technology simplifies this process at a high-fidelity level, circumventing the need for a physical medium [47].

Barr and Juricic [48, p. 269] have already proclaimed that “the designer of the future will work in cyberspace, a world of virtual reality where laser beams paint the world view directly onto the designer’s retina.” This prediction aligns with the development. However, it cannot yet be stated that VR has been fully integrated into ID education. Hence, to comprehend the reasons underlying this situation, an exploratory study [33] was conducted to uncover insights from ID students and instructors regarding the utilization of VR in ID education. This paper presents an expanded version of the qualitative part of that study, discussing the findings in comparison with similar studies.

III. Related Works

To determine previous works related to the use of VR in ID education, all English-language papers and proceedings indexed by Scopus and Web of Science up to 2023 that included the terms "virtual reality," "industrial design," and "design education" in their titles, abstracts, or keywords were reviewed. As a result of this literature review, which excluded review papers and the conference proceeding [33] upon which this study is based, it was found that there is a limited number of studies (a total of 9 studies) directly related to the use of VR in ID education.

This literature review shows that; Liang *et al.* [49] explored the characteristics of an ideal VR system tailored for ID students, Jimeno-Morenilla *et al.* [50] investigated the methodological applications of VR in ID education, Camba *et al.* [51] examined how VR can enhance student presentations and enrich the delivery of design information through 3D visualizations, Shih *et al.* [52] scrutinized the challenges and precautions associated with using VR in ID education, Evans and Söderlund [53] compared 2D and 3D design tools when co-designing prototypes in an immersive virtual reality collaborative environment, Huang *et al.* [54] explored the integration of VR technology into traditional 3D modeling education, and Banerjee *et al.* [55] probed whether VR can enhance the learning experience for developing model-making skills in ID education.

However, these studies are based on certain presuppositions [5]. In the study by Liang *et al.* [49], it was assumed that the reason VR has not yet been commonly used in ID education is the lack of a design-oriented VR system. Jimeno-Morenilla *et al.* [50] attributed this situation to the absence of a developed methodology for using VR in ID learning. Camba *et al.* [51] assumed that using VR in design education can be facilitated by integrating a course into the educational program, aiming to teach such technologies. Shih *et al.* [52] conducted their study under the assumption that VR is solely a drawing tool. Similarly, [53]–[55] considered VR as a 3D modeling and/or prototyping tool. However, VR can also be employed in ID practice for different purposes, such as getting inspired, sketching, design demonstration, collaboration, ergonomic evaluation, etc. [5], [56].

On the other hand, AL Jahwari *et al.* [57] and Bernardo and Duarte [58] tried to understand how VR technology impacts ID education. However, Bernardo and Duarte [58] questioned this issue only from the perspective of educators and, from the outset, assumed that the limited use of VR in ID education is due to the technology not yet being at a sufficient maturity level. Unlike them, AL Jahwari *et al.* [57] conducted their

Fig. 1. Installation of VR stations within the conference hall.

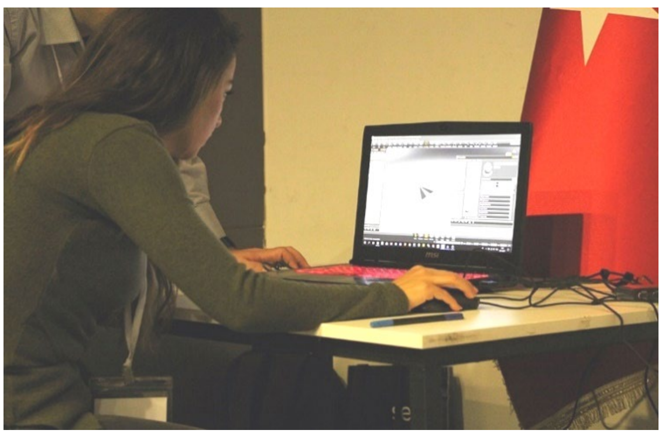

Fig. 2. A participant preparing a 3D model for VR experience using VRED.

Fig. 3. A participant experiencing a 3D model in the VR environment.

study by focusing on only students' perceptions.

As a result, none of these studies present a holistic view to discuss the acceptance of VR use in ID education and/or a comprehensive understanding of why VR technology with headsets has not been widely used in ID education yet. This paper was written by addressing this gap in the relevant literature.

IV. Methodology

This paper is structured around an analysis of qualitative data based on ID students' and instructors' opinions about using VR in ID education. These steps were followed in the data collection and analysis process:

1) Inviting ID students or instructors,
2) Introducing VR technology to them,
3) Performing a trial session to enable them to have a VR experience associated with ID,
4) Collecting data via a questionnaire and a group discussion session,
5) Analyzing the data with descriptive statistics and content analysis methods.

The first three steps were planned and executed to familiarize the participants with the technology in question and provide them with hands-on experience. This approach was necessary as it was not possible to find participants who had any prior experience using VR in ID education. At the time this study was conducted, there were no ID departments in Turkish universities that utilized VR in their educational settings.

A. Inviting participants

A call for participation was made by sending an invitation letter to all ID departments in Turkey. From 10 out of 26 universities in different cities, 38 participants, including 26 students and 12 instructors, registered and participated. They were also asked to bring a 3D model that they created using computer-aided design (CAD) software, such as Rhinoceros, Solidworks, 3ds Max, AutoCAD.

B. Introducing VR technology

A conference hall at Istanbul Technical University was used for this study. Participants were briefly informed about topics such as what immersive VR is and its usage in design and production processes through presentations by two experts from Autodesk and PENTA Technology in this hall.

C. Performing the trial session

Two VR setups were installed on two opposite sides of the scene platform in the hall, and they were made ready for use before the trial session (Fig. 1). In this study, HTC Vive headsets (Developer Edition) were used as hardware, and Autodesk VRED 2018 was used as software. A room-scale setup was done for the VR experience.

In this trial session, first, the process of importing a 3D model into the VRED software, transforming it, and assigning materials to the model in VRED (Fig. 2), and how to experience the scene with a 3D model using the HTC Vive platform (Fig. 3) were demonstrated step-by-step. Participants were then asked to follow these steps using the 3D models they brought. Each participant's trial session lasted approximately 3 to 5 minutes.

D. Collecting data

After the trial session, participants were asked to fill out an online form. Then, a group discussion session was held with them.

1) Online form

The online form used in this study consists of two sections: participant profile and open-ended questions.

The participant profile part includes five questions with multiple choices regarding age, sex, educational status, current position in the affiliated university (student or instructor), and familiarity with the VR equipment used in the study.

Two open-ended questions, asking participants to write their positive and negative opinions about using this type of VR technology in ID education, were added to the end of the form so that they could express their opinions individually in an unrestricted way.

2) Group discussion

Group discussions are a practical way to collect data from several people who share common experiences about a specific topic and focus on their shared meanings all at once [59]. Additionally, people often strive to express their opinions more clearly and understandably when speaking in front of a community. Therefore, a group discussion session with participants was conducted as the final part of the study. The aim of this part was to reveal the participants' positive and negative opinions verbally and to capture sentences explaining the reasons behind their opinions. In this discussion session, which lasted for 35 minutes, two moderators were employed. One moderator was responsible for ensuring the session progressed smoothly, while the other was responsible for ensuring that all participants who wanted to talk were included, that discussed issues were relevant to the research subject, and that the session was not dominated or forced by any participant. This session was recorded with both a video camera and a sound recorder.

TABLE I
GENDER DISTRIBUTION OF PARTICIPANTS

	Female	Male
Student	20	6
Instructor	6	6
Total	26	12
Percent	68.4	31.6

TABLE II
GRADE DISTRIBUTION OF STUDENTS

	Number	Percent
2nd Grade	3	11.5
3rd Grade	3	11.5
4th Grade	20	76.9

E. Analyzing the data

To analyze the collected data, first, the verbal data derived from the group discussion session was transcribed. Then, the written answers given to open-ended questions and this transcription were analyzed together, both quantitatively and qualitatively, using the content analysis method. The content analysis was conducted by following the steps outlined in the hands-on guide published by Erlingsson and Brysiewicz [60]. In this analysis, if a participant expressed a sentence more than once, that sentence was treated as if it had been stated once by that participant.

V. RESULTS

A. Participant profile

According to the analysis of participant profiles, 6 out of 12 instructors and 20 out of 26 students are female (Table I). Among the students, 20 are in the 4th grade, 3 are in the 3rd grade, and 3 are in the 2nd grade (Table II). The age range of the instructors is 26 to 56, while the students' ages span from 19 to 26. Additionally, out of the total 38 participants, 17 were not familiar with immersive VR technology, 18 had limited familiarity, and 3 were highly familiar. It is essential to note that in this context, "familiarity" refers to their knowledge of the VR equipment used in the study, not their experience with it in ID practices. None of the participants had previously utilized this type of VR equipment in their work related to ID before this study. The degree of familiarity among participants stems from their experiences in gaming and/or entertainment.

B. Content analysis results of the written and verbal data

The quantitative content analysis of written and verbal data was conducted through a general categorization of opinions as either negative or positive, based on condensed interpretations of the verbatim data. The goal of this analysis was to reveal the overall attitudes of both ID students and instructors toward the utilization of immersive VR technology in ID education. While Fig. 4 provides an overview of the attitudes of all participants, Fig. 5 and Fig. 6 separately depict the attitudes of instructors and students. In Fig. 4, it is evident that participants expressed 37 different sentences containing positive opinions a total of 101 times, whereas they expressed 43 sentences

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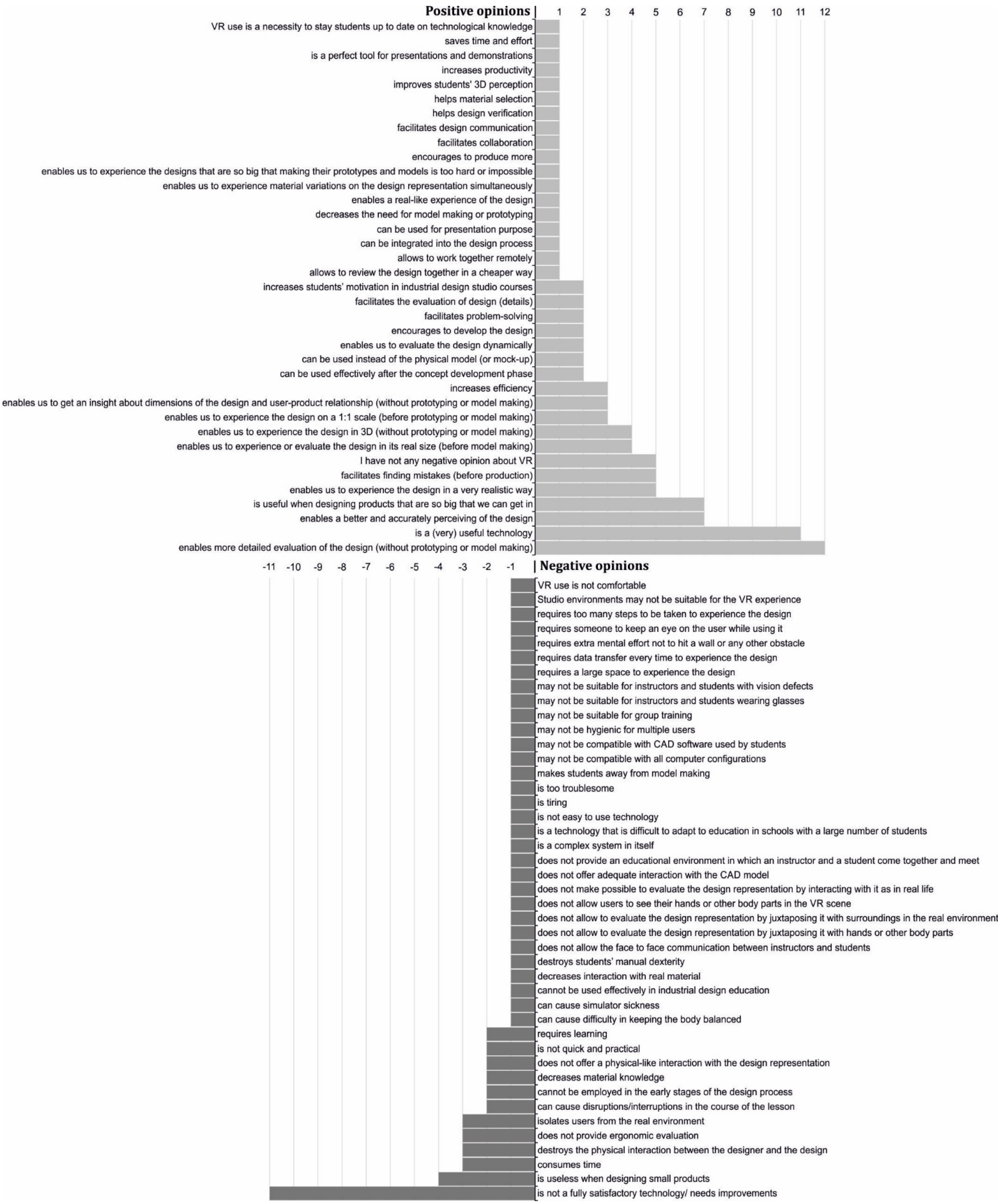

Fig. 4. Results of the quantitative content analysis of all written and verbal data.

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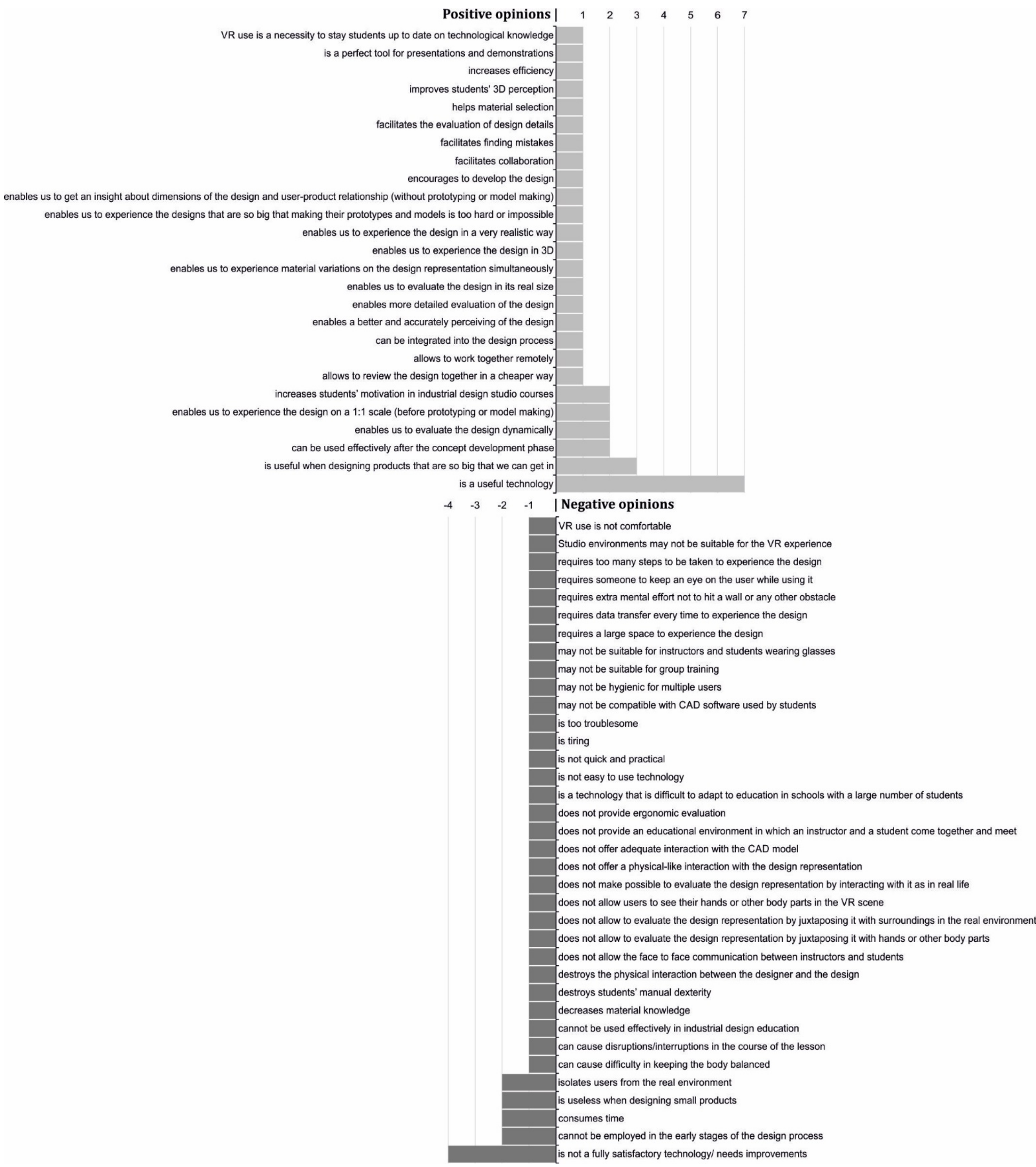

Fig. 5. Results of the quantitative content analysis of the instructors' verbal and written data.

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Fig. 6. Results of the quantitative content analysis of the students' verbal and written data.

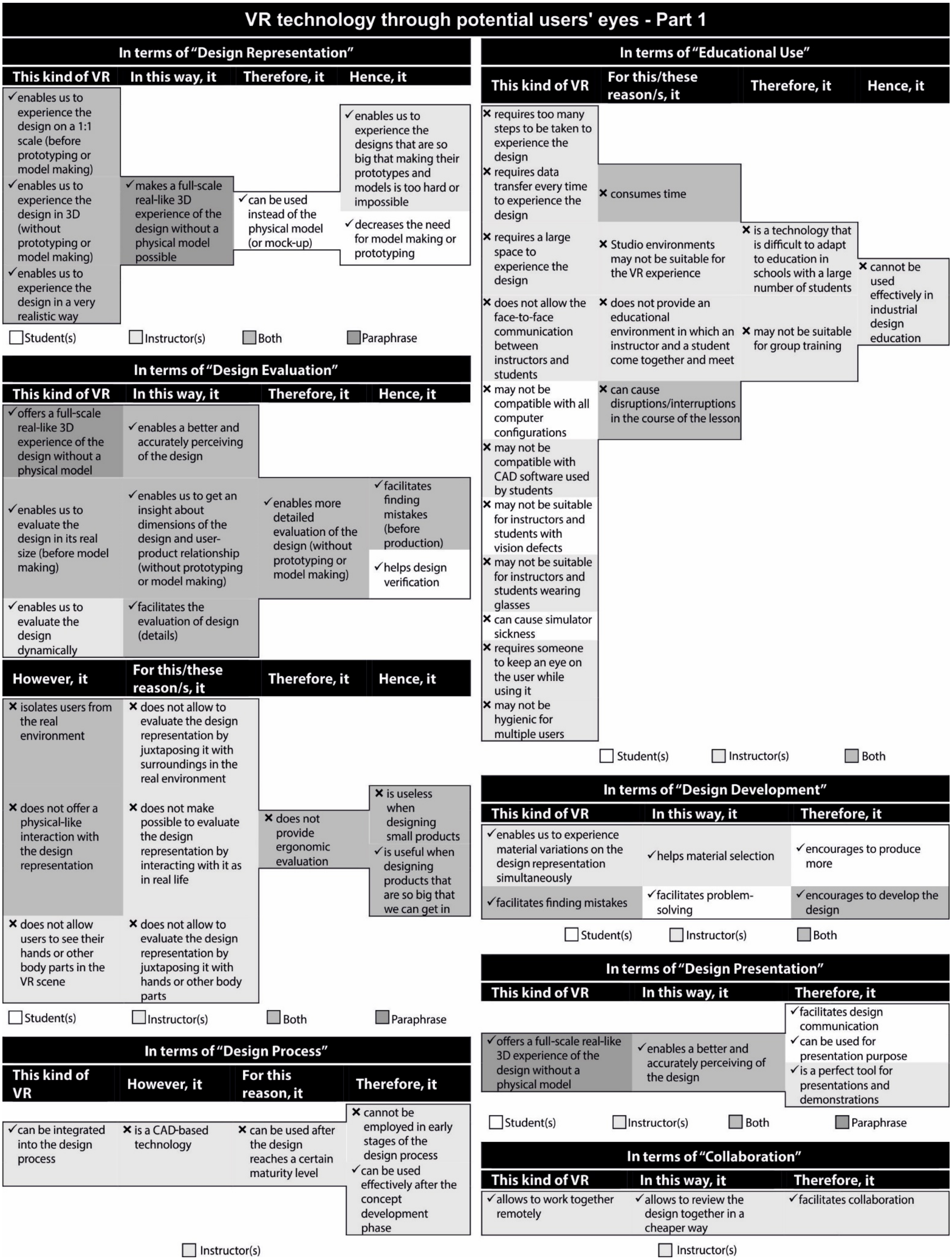

Fig. 7. VR technology through potential users' eyes – Part 1.

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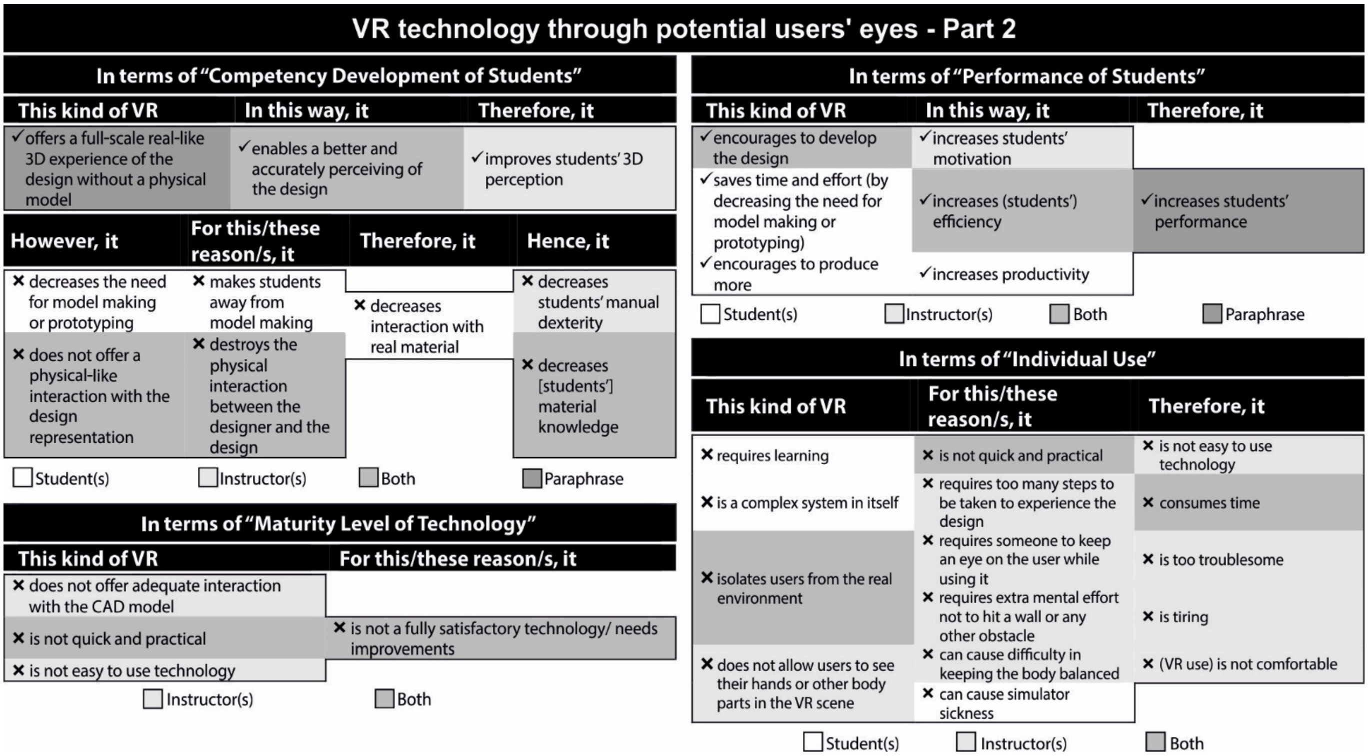

Fig. 8. VR technology through potential users' eyes – Part 2.

containing negative opinions a total of 70 times. On the other hand, out of these 37 sentences with positive opinions, 26 were expressed by instructors a total of 38 times, and the remaining 23 were articulated by students, amounting to 63 times. Meanwhile, among the 43 sentences containing negative opinions, instructors expressed 36 of them a total of 43 times, while students expressed 17 of them, tallying 27 times (Fig. 5 and Fig. 6). Based on the outcomes of the quantitative content analysis of both written and verbal data, it can be asserted that instructors exhibited a slightly negative attitude toward the use of VR in ID education, whereas students demonstrated a positive attitude.

This analysis not only unveiled the participants' assessments of the use of VR in ID education but also demonstrated that these assessments can be correlated with 11 categories. Therefore, the perceptions and interpretations of participants' thoughts and the reasons behind their thoughts are presented separately below, based on these categories derived from the collected data.

Regarding *"Design Representation"*, participants believe that VR provides a comprehensive and lifelike 3D experience of designs without the need for a physical model. It allows us to experience a design representation in an incredibly realistic way, on a 1:1 scale, and in full 3D, eliminating the necessity for prototyping or physical model creation. Therefore, it has the potential to replace the use of physical models or mock-ups. This not only reduces the demand for model-making or prototyping but also enables us to experience designs whose sizes are so big that making their prototypes or models too challenging or even impossible (Fig. 7).

Regarding *"Design Evaluation"*, on one hand, participants believe that VR provides valuable insights into the dimensions of a design and its user-product relationship without the need for prototyping or model-making. It enables a more accurate perception of the design, making it easier to evaluate design details by offering a full-scale, realistic 3D experience of the design without a physical model. This feature allows them to assess the design in its actual size and dynamic context, leading to a more thorough evaluation without the need for prototyping. This capability also aids in error detection and design verification. On the other hand, they feel that VR has limitations. It isolates users from the real environment and lacks a physical-like interaction with the design representation. Users cannot see their hands or other body parts in the VR scene, and this hinders the evaluation of the design as they would in real life. Additionally, VR does not allow for the juxtaposition of the design representation with hands, body parts, or real surroundings, making ergonomic evaluation challenging. Hence, participants consider VR useless when designing small products, despite its utility being evident for designs of such immense size that one can physically enter them (Fig. 7).

Regarding *"Design Development"*, potential users believe that VR aids in material selection by allowing us to experience simultaneously different material variations on a design representation. Additionally, it facilitates problem-solving by making it easier to find mistakes. Therefore, they perceive VR as a catalyst for increased productivity and design development (Fig. 7).

Regarding *"Design Presentation"*, participants believe that VR, by offering a lifelike 3D experience of the design on a full-scale without the need for a physical model, not only

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enhances design perception but also serves as a valuable tool for design communication and design presentation purposes. It is seen as an ideal tool for effective presentations and demonstrations (Fig. 7).

Regarding *"Design Process"*, instructors, while acknowledging that VR can be integrated into the design process, emphasize that it is a CAD-based technology best utilized after the design reaches a certain level of maturity. Consequently, they believe that VR is not suitable for the early stages of the design process and can be effectively employed after the concept development phase (Fig. 7).

Regarding *"Collaboration"*, instructors consider that VR facilitates collaborative work by enabling remote collaboration and cost-effective design reviews (Fig. 7).

Regarding *"Competency Development of Students"*, participants have conflicting views. On one hand, they believe that VR enhances students' 3D perception by providing a better and more accurate understanding of the design. However, on the other hand, they argue that VR reduces the need for model-making or prototyping, distancing students from hands-on work and erasing the physical interaction between the designer and the design due to the lack of a physical-like interaction with the design representation. Consequently, they suggest that decreased interaction with real materials in VR could not only impair students' manual dexterity but also limit their knowledge of materials (Fig. 8).

Regarding *"Performance of Students"*, participants believe that VR has the potential to boost students' motivation, efficiency, and productivity. They argue that it encourages students to enhance their design work, leading to increased production. Additionally, it is seen as a time and effort saver due to reduced reliance on model-making or prototyping (Fig. 8).

Regarding *"Maturity Level of the Technology"*, participants think that VR is not fully satisfactory and requires improvements because it does not provide adequate interaction with the CAD model, lacks speed and practicality, and is not user-friendly enough (Fig. 8).

Regarding *"Individual Use of VR"*, participants find it complex, necessitating a learning process, and note that it isolates users from their physical surroundings, preventing them from viewing their own hands or body parts in the VR scene. Due to these factors, participants perceive VR as neither quick nor practical. It involves too many steps to engage with a design, requiring constant supervision during use to prevent accidents, demanding extra mental effort to avoid collisions with walls or obstacles, posing challenges to maintaining bodily balance, and even potentially causing simulator sickness. Consequently, it is viewed as a less user-friendly technology that consumes time, presents significant challenges, is fatiguing, and ultimately leads to an uncomfortable VR experience (Fig. 8).

Regarding the "*Educational Use of VR"*, participants believe that it consumes time and can lead to disruptions in the lesson due to the need for numerous steps to experience a design, frequent data transfers, and the requirement for supervision during use. They note that it does not create an educational environment conducive to face-to-face communication between instructors and students. Additionally, they consider VR unsuitable for in-studio use due to the space it requires for experiencing designs. They also point out that it might not be compatible with all computer configurations and CAD software used by students, may not suit individuals with vision impairments or those wearing glasses, may not maintain hygiene standards when used by multiple users, and can lead to simulator sickness. As a result, participants suggest that VR may not be suitable for group training and could be challenging to integrate into educational settings with too many students. They conclude that VR might not be effectively utilized in ID education (Fig. 7).

VI. Discussion

A. On the results of the content analysis of written and verbal data

The written and verbal data collected from participants underwent both quantitative and qualitative content analysis. The quantitative analysis aimed to uncover the attitudes of ID students and instructors toward the utilization of VR in ID education. The results indicated that instructors approached the technology cautiously, whereas students displayed a more positive attitude.

On the other hand, the qualitative content analysis delved into the underlying reasons for these positive or negative attitudes. Based on the outcomes of this analysis, it can be inferred that participants' positive views are primarily rooted in VR's ability to provide a full-scale, real-like 3D experience of the design without the need for a physical model. This feature is perceived as beneficial for competency development, performance enhancement, design representation, evaluation, development, and presentation.

However, there is a concern that the reduction in the need for modeling or prototyping could lead to students distancing themselves from model-making, resulting in a decline in their manual skills. Likewise, the absence of physical-like interaction with the design representation is seen as a drawback, as it disrupts the physical connection between designers and their designs. This limitation not only poses a threat to students' material knowledge but also renders VR less useful when designing small products.

Aside from the aforementioned considerations regarding the utility of VR, it becomes evident that participants' negative opinions largely revolve around its ease of use. These opinions primarily stem from the fact that VR requires users to wear a device on their eyes, leading to isolation from the real environment. Additionally, it demands installation, learning, and a significant amount of physical space to experience the design. Consequently, participants view VR as a technology that is not user-friendly, potentially cumbersome, tiresome, and time-consuming for individual use.

In terms of educational application, VR is perceived as a challenging technology to integrate into ID education. It is believed that the technology may face difficulties in adaptation within this educational context, leading to the conclusion that it may not be effectively employed in ID education.

In conclusion, it can be stated that VR technology has not fully fulfilled certain expectations of ID students and instructors, particularly in terms of quick, practical, and user-friendly interaction with virtual objects in a way resembling physical interactions.

B. By revisiting the related works

As mentioned in Section III (Related Works), Liang *et al.* [49] argue that a design-oriented VR system is required for the wider adoption of VR in ID education. The findings pertaining to "design evaluation," "individual use," and the "maturity level of technology" support this assertion. Developing VR systems that enable physical-like interactions with design representations in the VR environment, allowing users to see their hands and other body parts, is necessary to ensure an easy-to-use experience.

Camba *et al.* [51] propose integrating a course that teaches such technologies into the curricula of institutions that offer ID education. In alignment with this proposal, this study demonstrates the necessity to address the learning requirements for VR technology. Furthermore, although not explicitly stated by the participants, it can be inferred that the learning needs of ID educators for this technology should also be considered.

The studies [52]–[55] consider VR as a drawing, 3D modeling, and/or prototyping tool. However, participants believe that VR is primarily a presentation tool. This aspect should be considered when developing the methodology, which Jimeno-Morenilla *et al.* [50] mentioned as lacking.

On the other hand, there is a significant overlap between the findings of this study and the findings of studies [57] and [58]. For example, there is a shared belief that VR technology is a useful tool in ID education in many ways, but it may not be as effective in the design process of small products, and there are concerns about it reducing students' engagement with materials and hands-on activities. However, in contrast to these previous studies, our research highlights that one of the major obstacles to the widespread adoption of VR technology is the large number of students in classrooms, particularly in educational institutions in developing countries, and the need for a relatively large physical space for its usage.

C. On the possible biases in the results

VR technology was a new technology for all participants in this study and most of them had little or no familiarity with the equipment used. For this reason, they might have exaggerated their assessments. In other words, their responses may have been influenced by the novelty effect of VR technology. On the other hand, participants tried to experience the CAD models they brought with them in the VR environment. These CAD models were in different sizes and had different complexity levels. This situation, as well, may have influenced their responses. However, both circumstances are the circumstances that may emerge if VR technology is tried to be used in ID education under real conditions. From this point of view, they can be considered as representations of real-life conditions within the study outcomes, not circumstances that cause biases in the results.

VII. Conclusion

This study demonstrates that ID students and instructors have reservations about the use of VR in ID education. These concerns primarily revolve around the potential negative impacts of VR use on the development of students' competencies in manual dexterity and material knowledge. Additionally, there are questions about its effectiveness in ID education, especially in schools with a large number of students and limited space available for implementing this technology.

On the other hand, this study presents a comprehensive and holistic understanding, which is lacking in the existing literature, of why VR technology with headsets has not been widely used in ID education yet. Additionally, it provides a foundation not only for discussions on the future of VR in ID education but also for further studies on the integration of VR in ID education.

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