Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 5, 1400-1412
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i5.1843

User experience testing methods: Conclusions from the literature

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Abstract: Industry 4.0 focuses on the digitalization of production processes and technological innovation. The concept of Industry 5.0 puts the focus on human-centricity, sustainability, and resilience at the heart of research and development and innovation (R&D&I) processes to allow industry to serve humanity with a long-term vision that considers planetary boundaries. Replacing the technology-driven approach with a fundamentally human-centric approach requires a deep understanding of the working environment and workers interacting with machines to optimize worker well-being, working conditions, and job outcomes. Analyzing computer work User eXperience (UX) in industrial environments is vital. However, user perceptions are usually hidden and a challenge to detect. Therefore, measuring and monitoring perceptions, emotional reactions, subjective elements, preferences, and attitudes in the relationships between usability, work performance, and workload is crucial. This study provides conclusions of a literature review on user experience studies focusing on UX testing methods and the disciplines linked to industrial diversification. Based on literature analysis, it identifies UX testing methods and create own grouping to analyze them. It also examines the disciplinary context of user experience testing.

Keywords: *Efficient digitalization, Industry 5.0, Sustainable growth, User experience.*

1. Introduction

Human-machine interactions are increasingly prominent in our technology-infused daily lives. The pragmatics branch of semiotics [1] is also notable. User eXperience (UX) significantly influences the performance of human-machine interactions. Accordingly, UX studies are becoming ever more essential in ensuring these interactions have positive connotations and are, thus, effective.

This study explores the literature related to UX studies before major asset acquisition (hardware, software, and the associated learning costs and the determination caused by investment). The two examined research questions (RQ) are:

1) What are the identifiable UX testing methods, and how widespread are they?

2) Are UX methods linked to a specific discipline, for example, marketing, psychology, computer science, or other disciplines?

2. Literature Review

2.1. Industry 5.0

Rapidly evolving digitalization supplies companies with new tools, affects work processes via increasing efficiency, and, in some sectors, dramatically changes work environments and required competencies. Business competition is transforming, and supply chains are becoming more intertwined.

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Concepts proclaiming new industrial revolutions are increasingly ubiquitous, yet few include the characteristics of previous industrial transformations [2]. Industry 4.0, originally the umbrella concept of a government initiative to renew German industry by focusing on production processes, digitalization, and technological innovation [3], has been spreading explosively since 2011. Industry 4.0 is prevalently used synonymously with the Fourth Industrial Revolution, hence the acronym IR, which this article also uses. IR 4.0 is a vision of modular networked production, where factories, workpieces, and plants communicate with each other, for example, control the processes themselves. These developments are causing changes in all aspects of life [4].

After the initial hype following the launch of the new technologies dissipated, it became increasingly clear that technology-focused terminology without objectives did not provide the correct orientation to related policies. Recognizing this, the European Commission began promoting the Industry 5.0 concept in 2020. As Figure 1 illustrates, IR 5.0 utilizes a three-pronged focus on human-centricity, sustainability, and resilience. It places this at the heart of IR 5.0 technologies and processes to allow industry to serve humanity with a long-term vision considering planetary limits [5].

Figure 1.
The pillars of IR 5.0 [6].

In the author's view, IR 5.0 cannot be construed as another industrial revolution but as IR 4.1, which shifts the technological perspective towards current global challenges and provides the technology with a purpose and aim. For example, the opportunities and challenges of testable artificial intelligence (AI) language models, readily available since the end of 2022, are firmly reflected in public discourse and academia. However, studies on IR 4.0 technologies have already included AI technology within IR 4.0 [7], indicating that the most promising technology — which started to be used widely in the Industry 5.0 period — was also present in the Industry 4.0 concepts of the 2010s. IR 5.0 does not comprise any new technology. It merely adds focal points that complement IR 4.0. Thus, it is not a radically new version (5.0) in the numbering logic of software products but rather a substantial correction or upgrade of the existing version (4.1).

2.2. The Pillars of Industry 5.0

2.2.1. Examining the Pillars Clarifies Current Economic Challenges

Recent unforeseen crises such as the COVID-19 pandemic and the Russia-Ukraine war have highlighted global supply chain vulnerability and the potential for longer-term economic impacts. Fortifying the first pillar —resilience —is vital. Kézai and Kurucz [8] researched the Visegrad countries and discovered that countries with fortified start-up ecosystems were more resilient during the COVID-19 crisis.

Nearly everyone experiences global warming-induced weather anomalies. Sustainability, the second pillar, has become a slogan in virtually all areas of economic life [9], [10], [11], [12]. Embedding IR 5.0 in the concept reflects a techno-optimistic view that technological innovation can solve these problems without implementing extensive changes to the profit-driven economy [13]. Keresztes [14] noted the essentiality of improving knowledge transfer by strengthening the links between innovation actors, particularly in academic science and industry, and developing activities and collaborations supporting the R&D&I process. Previous displays of sustainable behavior (aspiration) were primarily about opportunity and positioning; today, they have become virtually mandatory [15]. Consequently, management actively incorporates sustainability criteria into decision-making processes and organization operations [16].

Human centricity is the third IR 5.0 pillar, which envisages human-machine interactions as complementary rather than competitive. Machine collaboration should entail higher quality human work. Technology will replace some jobs, but it will also create many jobs as workers move into new roles in the same workspace with collaborative robots (cobots), augmented or virtual reality, wearable, smart devices, big data [17], drones and unmanned aerial vehicle (UAV), additive manufacturing, and AI. Analogously, these processes will require skills transformation. Figure 2 shows the most recent World Economic Forum [18] survey data, revealing that narrowly defined technology skills represent only a minor part of the top 10 skills. In addition to digital skills, digitalization entails many essential requirements to operate effectively within new human-machine collaboration roles. Thasan et al. [19] observed the link between automation and a highly skilled workforce in manufacturing companies.

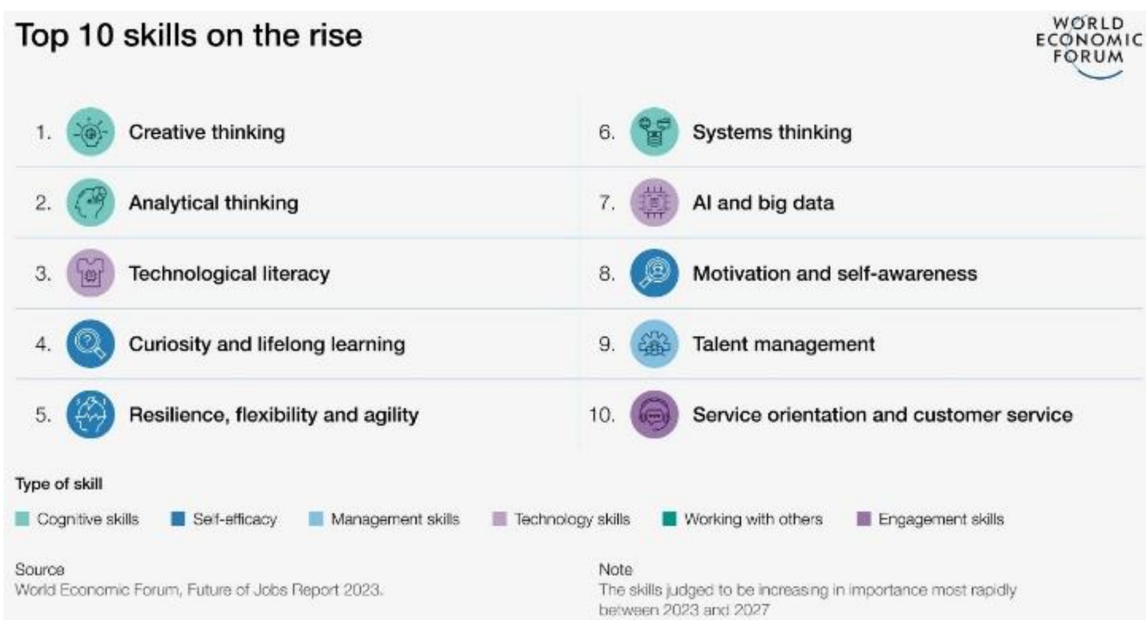

Figure 2.
Skills and attitudes on the rise [18].

In addition to technological factors, organizational factors and the innovation capacity of employees must also be brought into focus [20]. Replacing a technology-driven approach to development with a fundamentally human-centered approach warrants a deep understanding of work environments where employees interact with machines. Optimizing worker well-being, working conditions, and work outcomes is indispensable. Human factors engineering (HFE) takes a multidisciplinary approach to the human-technological environment relationship and strives to design and develop human-centered systems by understanding user characteristics, capabilities, and limitations [21].

2.3. User eXperience (UX)

Analyzing the UX of computing in an industrial environment is vital to developing human-centered digitalization. Since user perceptions are typically hidden and challenging to detect, measuring and monitoring perceptions, emotional reactions, subjective elements, preferences, attitudes, and the relationship between usability, work performance, and workload is crucial.

Human-Computer Interaction (HCI) concentrates on implementing and evaluating collaborative, interactive computing systems, including safety and efficiency [22]. The International Organization for Standardization (ISO) has a separate standard dedicated to this area – ISO 9241-210:2019 Ergonomics of human-system interaction – Part 210: Human-centered design for interactive systems [23]. UX constitutes a critical HCI study area.

According to ISO 9241-210:2019, UX comprises the perceptions and reactions of a user using a system, product, or service and includes user emotions, beliefs, preferences, perceptions, behavior, and performance. The experience extends into post-use. The user's previous experiences, attitudes, skills, and personality also affect these perceptions and reactions. UX is not synonymous with usability, which analyzes whether a system, product, or service effectively and satisfactorily achieves the goals defined by individual users within the context of a specific use.

Therefore, UX is much more than user-focused software testing. UX is also user experience design, a more accurate way of saying that user experience is not merely an afterthought but a part of the design process. At the same time, developers have no direct influence on the subjective 'internal experience' of the user, which, as described above, is influenced by several individual factors present in the user. UX design in computer applications is more than user interface design (UI), which is a vital part of the UX but does not determine it.

Fatima and De Moor [24] created the Sustainable User eXperiences Enabled Human-centered (SUXEH) framework, which incorporates human psychological needs into the early stages of software development. In this concept, the user experience mediates human psychological needs, which is integrated into the entire development process. The authors demonstrate the concept through a specific case study.

UX is often researched with the technology acceptance model (TAM). The TAM model was originally proposed by [25], and later the original version was improved several times (TAM2, TAM3).

According to the original model, the user's perceived ease of use and usefulness determines the acceptance of a technology. Hornbæk and Hertzum [26] reviewed 37 publications that examined how TAM and UX models overlapped to investigate the experiential aspect of HCI. They found that most reviewed studies are unconnected to specific use episodes, thus bypassing tasks as an explanatory variable and avoiding accurate measurement of UX that is sensitive to change. Mlekus et al. [27] introduced the User eXperience Technology Acceptance Model (UX TAM) to explore how features related to the user experience influence people's acceptance of new technology. Quynh and Truong [28] confirmed the need to extend the TAM(2)-model with social influence and perceived security factors in digital service contexts if customer attitudes are to be measured.

3. Methodology

The study was initiated using a systematic literature review (SLR). SLR examines previous studies by reviewing relevant literature based on several defined stages [29]. The process identifies, assesses, and interprets research materials to answer several RQs [30]. We employed the Scopus database for the identifying stage. Scopus connects to many relevant, high-quality databases, including Web of Science, ScienceDirect, Emerald Insight, SpringerLink, IEEE Xplore, ACM Digital Library, PubMed, and Wiley Online Library. We used the *user AND experience OR UX* search term with the *method Or instrument OR etc. based on* [31] terms. Each option can be combined separately, for example, by using these terms of specific methods separately: NASA Task Load Index (TLX); AttrakDiff; User Experience Questionnaire (UEQ); instrumental measurement; heart rate; blood volume pulse, facial expression, eye-tracking, brain activity; EEG, galvanic skin response; GSR; electrodermal activity; EDA; postural comfort; RULA, etc.

At this research stage, we found that several literature reviews on user experience methods have appeared in recent years, including [29], [30], [31], and [32], who specifically reviewed the literature on user experience studies using instrumental measurements. Consequently, we considered it unnecessary to conduct a further systematic literature review. Research questions can be answered by building on existing studies and analyzing unaddressed questions. Studies that build on each other in this way also strengthen the cohesion of science, which is also crucial. A literature mapping was used with the first RQ to identify recent research directions, including relevant studies cited by the results of the above searches. We drew new conclusions to answer the second RQ through our criteria-based analysis included in the systematic literature reviews from recent years.

4. Result and Discussion

4.1. Research Deliverable 1

This section addresses the first RQ which aims to identify UX testing methods and how widespread they are.

UX conjures images of human interactions with a computer interface. However, a broader area of user experience research comprises measuring physical and mental workloads and improving physical, cognitive, environmental, and organizational ergonomics [35]. Identifying potential physical and mental stressors that can dampen operator performance is crucial with heavy workloads.

Nur et al. [32] list several types of user metrics, including performance, issue-based, self-reported, interaction, emotion, stress, and behavioral and physiological. The literature uses these elements more widely, but the performance and issue-based approaches focus on usability. Furthermore, emotion, stress, or behavior are also issues in the self-reported metric, implying an overlap. Via a literature review, the present study provides a slightly different breakdown of the relevant testing methods (focusing on who to measure, not what to measure). Studies can investigate user experience in three ways:

1) By evaluating the impact of work organization, for example, cognitive workload, interaction, physical demands, working environment, and equipment required.

Even if not closely related to the analyzed activity, external environmental elements affect user experience measurements and, where relevant, user experience, implying that it may be necessary to analyze work organization and related external factors such as cognitive/mental workload, interactions, physical stress, working environment, and equipment required. Field observation and related analysis can be used to evaluate and improve these impact factors. UX optimization aims to improve some combination of physical, cognitive, environmental, and organizational ergonomics [35].

2) Evaluation of the user experience as perceived by users, for example, interviews, self-designed or standardized questionnaires such as NASA Task Load Index (TLX), AttrakDiff, System Usability Scale (SUS), and User Experience Questionnaire (UEQ).

Most studies used a self-reported method, with the self-assessment questionnaire being the most common [32], [33]. Questionnaires can be self-designed or standard; the latter is the most commonly used [32].

With a nearly 40-year history, the NASA Task Load Index (TLX) [36] ranks among the oldest questionnaires. Nakamura et al. [37] identify the AttrakDiff and User Experience Questionnaire (UEQ) as two of the most well-known and used standardized UX evaluation questionnaires and compare them in a longitudinal study. The results indicate that UEQ could capture the nuances of the variation of UX better than AttrakDiff, leading to more consistent results due to the fine-grained dimension.

3)Evaluation of user experience measured by instrumental measurements such as Heart rate (HR), heart rate variability (HRV), heart rate variability (HRV), inter-beat intervals (RR), Blood Volume Pulse (BVP), Facial expression recognition, breathing rate (BR), eye activity (e.g., pupil diameter (PD), blink rate, gaze fixation, duration, pointing), brain activity (e.g., electroencephalogram (EEG), magnetoencephalogram (MEG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), brain functional connectivity (FC)), galvanic skin response (GSR), electrodermal activity (EDA), postural comfort (e.g., human joint angles / Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Workplace Ergonomic Risk Assessment (WERA)).

Instrumental studies extend back several decades [38]. Instead of subjective (e.g., interview, questionnaire) measures of perception, they focus on observing neurological and physiological (psychophysiological) measures that human emotions, perception, and behavior involuntarily elicit. The typical advantages of these studies include the ability to comprehensively examine the whole process, the reliability of the involuntary responses, and the possibility of multidimensional analyses [34]. The list above summarizes the most common psychophysiological measures individuals cannot willingly regulate.

Conclusions that are more objective about arousal intensity, stress detection, cognitive load, and emotional engagement can be drawn from reactions elicited at the subconscious level than from the self-reported method. Higher arousal can be associated with higher recall, and engagement levels may lead to better recall and persuasion [39] according to perspicuity, immersion, stimulation, loyalty, and trust as significant aspects of user experience [40], [41].

González-Rodríguez et al. [42] demonstrated that facial expression recognition is a suitable tool to measure customer satisfaction in the tourism industry and can complement or replace self-completion questionnaires. Several studies investigated eye-activity measurement [43] and found that such measurements can provide feedback on the user's internal processes, cognitive processing [44], and the perceptual characteristics of the test object by measuring gaze fixation, pointing, and duration [45], [46].

Mészáros and Nyikos [47] provide a more detailed practical summary measuring brain metabolic and electrical activity in neuromarketing. Several studies have included the operation of EEG measurements [48], but the methodology of these studies is unknown, particularly in terms of specific instruments and related expertise. Based on information provided by the team leader, Réka Kissné Zsámboki, the University of Sopron research team, in consultation with a neurological specialist, completed studies unrelated to user experience. The studies concluded that simple solutions to determine the accurate placement of EEG devices (e.g., 'Ninja mask' with sensors) do not work satisfactorily. Finding optimal sensor locations requires specialist expertise to prevent sensors from being positioned in suboptimal places where they will still measure and provide evaluable data sets, inevitably resulting in inaccurate conclusions. Evaluating the signals returned by accurate measurements also requires medical expertise. Also, such data are more suited to observing dynamics than discerning content.

With the galvanic skin response (GSR) (and its synonym, the electrodermal activity (EDA)), we measure involuntary skin responses. The advantage of this method is that the device can be easily and faultlessly fitted without specialized expertise. The GSR measures the arousal to a stimulus, not the valence. Therefore, it is used infrequently on its own. Eye-tracking and facial expression recognition/analysis usually complement it. The disadvantage of the method is that the latency of GSR signals is 1–5 seconds, making it difficult to determine what stimulus triggered a given response. Further studies, e.g., post hoc interviews, may be needed. The GSR peaks per minute do not focus on individual moments but are a measure of the totality of an activity to measure the combined emotional impact. Kühn and Boshoff [39] investigated the effectiveness of storytelling in advertisements. They used GSR to monitor arousal and electroencephalography (EEG) to monitor emotional engagement. Islam et al. [49] used GSR signals to investigate the realism of different driving simulators.

Postural comfort measures can be used to monitor physical work in an actual work environment. Khamaisi et al. [35] examine heavy-duty work sequence manual operation tasks for pressure vessels manufacturing, with the usage of human joint angles (RULA), supplemented by monitoring and analysis of heart rate (HR), inter-beat intervals (RR), electrodermal activity (EDA) and pupil diameter (PD).

Instrumental studies are usually conducted in a controlled environment due to higher instrument requirements [32]. Combining instrumental and feedback methods (e.g., interviews and questionnaires) provides the most accurate results for a given user experience study, as highlighted by [35]. Grandi et al. [21] combined different instrumental measurements and standardized questionnaire results into a composite index.

Hinderks et al. [50] examined user experience methodologies that are embeddable in increasingly popular agile software development. Agile methodologies include elements that implicitly incorporate user experience into the development process [51], such as user stories that help to understand user needs and build them into product backlogs. However, these methodologies operate with a fixed framework, tight deadlines, and timelines, which helps explain why user experience analyses monitored by instrumental measurements are not widespread in agile development [50], [52].

4.2. Research Deliverable 2

This section addresses the second RQ – can UX be related to a specific field?

Several literature reviews on user experience methods have appeared in recent years, including [29], [30], [31], and [32], who specifically reviewed the literature on user experience studies using instrumental measurements. Consequently, we considered it unnecessary to conduct a further literature review.

The study of the field can be seen as a complementary analysis of the existing literature review. For this purpose, the literature reviewed by the above four reviews provides a basis. However, we excluded [33] because the databases and journals chosen for the literature review are exclusively technological. Also, the screening process did not include social sciences and other fields, so it was unsuitable for our research question. We also excluded [31] because the literature involved in the research was unidentifiable in the study or the technical report cited therein. We analyzed the studies included in the systematic literature review from the bibliography of the other two studies in the following way.

Nur et al. [32] included a total of 61 references from Scopus, Science Direct, IEEE Xplore, ACM Digital Library, and Emerald Insight databases. The research identifies the non-IT domain as Exclusion Criteria, which nuances the results below. Conference papers comprise most of the included works, with most conferences related to the information systems field, especially Human Factors in Computing Systems and Human-Computer Interaction, underscoring the interdisciplinary nature of the subject area between IT and Humanities. Of the journal articles included in the study, 24 are from journals listed in the Scimago Journal and Country Rank database. Table 1 presents the subject areas of these journals.

Table 1.
Scimago subject areas and journal reference categories of [32].

Subject area and category	Count
Agricultural and biological sciences	1
Agricultural and biological sciences (Miscellaneous)	1
Arts and humanities	1
Arts and humanities (Miscellaneous)	1
Computer science	25
Computer networks and communications	2
Computer science (Miscellaneous)	5
Computer science applications	5

Hardware and architecture	1
Human-computer interaction	5
Information systems	4
Software	3
Decision sciences	2
Information systems and management	1
Management science and operations research	1
Engineering	4
Biomedical engineering	1
Engineering (Miscellaneous)	3
Health professions	2
Health information management	2
Materials science	1
Materials science (Miscellaneous)	1
Mathematics	2
Theoretical computer science	2
Medicine	10
Geriatrics and gerontology	1
Health informatics	7
Medicine (Miscellaneous)	2
Psychology	1
Psychology (Miscellaneous)	1
Social sciences	10
Cultural studies	1
Education	2
E-learning	2
Human factors and ergonomics	1
Library and information sciences	2
Political science and international relations	1
Sociology and political science	1
Total	59

Source: Own construction based on [32], The total does not equal the number of journals because a journal can appear in more than one subject area and category.

Ten journals have a Hirsch index of at least 100. These typically appear in more than one subject area (e.g., computer sciences and social sciences). Table 2 shows the Q1–4 values of the included journal citations by subject. Each ranking represents the Q value realized in the year of article publication.

Table 2.
Q1–4 ratings in journal references used in [32].

Subject area and Q1-4	**Count**
Agricultural and biological sciences	1
Q3	*1*
Arts and humanities	1
Q1	*1*
Computer science	25
Q1	*7*
Q2	*7*
Q3	*9*

ISSN: 2576-8484
Vol. 8, No. 5: 1400-1412, 2024
DOI: 10.55214/25768484.v8i5.1843

Q4	*2*
Decision sciences	2
Q1	*1*
Q4	*1*
Engineering	4
Q1	*2*
Q2	*2*
Health professions	2
Q2	*1*
Q3	*1*
Materials science	1
Q2	*1*
Mathematics	2
Q3	*1*
Q4	*1*
Medicine	10
Q1	*4*
Q2	*3*
Q3	*3*
Psychology	1
Q1	*1*
Social sciences	10
Q1	*6*
Q2	*1*
Q3	*3*
Total	59

Source: Own construction based on [32], The total does not equal the number of journals, as a journal may have more than one subject area, category, and associated Q values.

Zaki and Islam [34] included 27 references from Google Scholar, SpringerLink, ScienceDirect, ACM Digital Library, Scopus, IEEE Xplore, PubMed, and Wiley Online Library. As before, most included studies are conference articles with a similar thematic focus. Of the included journal articles, 9 are from journals in the Scimago Journal and Country Rank database. The subject area of these journals is narrower than in the previous case due to the limited number of journals. However, several new subjects appear, including Business, Management, and Accounting (Marketing, Tourism, Leisure, and Hospitality Management); Neuroscience (Cognitive Neuroscience, Developmental Neuroscience); and Physics and Astronomy (Atomic and Molecular Physics, and Optics), with the associated categories in brackets, each appearing in one case.

Four journals have a Hirsch index of at least 100. These appear in several subject areas. Table 3 shows the Q1–4 values of the journal citations included in this study, divided by subject area. Each classification represents the Q value realized in the article publication year.

Table 3.
Q1–4 ratings in journal references used in [34].

Subject area and Q1-4	**Count**
Business, management, and accounting	2
Q1	2
Computer science	8
Q2	7

Q3	1
Engineering	4
Q1	3
Q2	1
Health professions	1
Q1	1
Neuroscience	2
Q4	2
Physics and astronomy	1
Q4	1
Psychology	2
Q1	2
Social sciences	7
Q1	5
Q2	1
Total	26

Source: Own construction based on [34], The total does not equal the number of journals because a journal may have more than one subject area, category, and associated Q values.

The analysis clearly shows that user experience studies in the information systems field – including literature research focused on neurological and physiological measures – are at the interface of several disciplines and combine this expertise. Humans are ultimately the UX study subjects; thus, including several human-focused disciplines is apt.

5. Conclusions

Investigating the two research questions has confirmed the validity of instrumental user experience studies. Observing involuntary reactions increases test objectivity and allows real-time monitoring of the whole process and more accurate identification of the factors influencing user experience. The most commonly employed methods are eye cameras, facial expression recognition, skin response measurement, and EEG. The latter has been discarded based on internal experience. Combining instrumental measuring with perceived user experience measuring (interviews, standard questionnaires) can be very effective.

The research studies connect to many disciplines, with humanities and life sciences contributing as much to user experience studies as computer sciences. Instrumental studies contribute even more, as demonstrated in the word cloud of the title of the studies included in the [34] literature review on neurological and physiological measures, where neuromarketing became the most prominent term, indicating that instrumental (neurological and physiological) studies of user experience are more often related to business disciplines than, for example, computer science.

Acknowledgments:
This article was completed within the TKP2021-NVA-13 framework, implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development, and Innovation Fund, financed under the TKP2021-NVA funding scheme.

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Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 5: 1400-1412, 2024
DOI: 10.55214/25768484.v8i5.1843