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Meta-theoretic Assumptions and Bibliometric Evidence Assessment on 3-D Virtual Worlds as Collaborative Learning Ecosystems

António Correia   **Fernando Cassola**   **Diogo Azevedo**   **André Pinheiro**
UTAD – University of Trás-os-Montes e Alto Douro, Vila Real, Portugal

Leonel Morgado
Universidade Aberta, INESC TEC, Lisbon, Portugal

Paulo Martins   **Benjamim Fonseca**   **Hugo Paredes**
UTAD, INESC TEC, Vila Real, Portugal

Abstract

Computer-supported online 3-D virtual world environments have been waxed and waned in interest and representativeness for supporting collaborative- and simulation-based practices. In a post-modern societal framework that requires inexpensive solutions for high-risk situations, research efforts in virtual worlds have developed a basis for understanding the use of virtual reality for multidisciplinary scenarios such as distance learning, training, therapy treatment, and social interaction. Complex relationships can be established simultaneously between several students functioning as integrated learning units using different media, and interacting with their physical environment in the context of real-world settings. In this context, a recurrently updated research agenda for virtual worlds can characterize the current needs at a systematic way. This paper presents a meta-analysis of 35 publications to identify gaps and opportunities for research in collaborative three-dimensional environments based on content analysis. At a general perspective, there is a lack of established approaches to measure the influence and research potential of sociocultural factors in virtual worlds' usage, autism spectrum and

other healthcare-related settings, learning outcomes, content characteristics, task support for groups and crowds, and online data collection.

1. Introductory Remarks

Virtual worlds and metaverse platforms have appeared in literature as viable solutions for learning, working and other real-world simulation tasks, expecting a large and growing impact on teaching and learning in higher education for the near future (Hew & Cheung, 2010). Virtual world platforms have been adopted in a vast range of application fields such as healthcare, military training, economics, urban planning, architecture, learning, or engineering (Jarmon et al., 2009). These hybrid virtual ecosystems provide an experience that transcends cultural, social, language, distance, and temporal limitations through different modes of interaction (Anstadt et al., 2011), supporting a vast set of collaborative learning strategies, methods, and activities within which every learner agent plays an essential role.

Identifying essential knowledge is becoming increasingly complex, and meta-analytic research endeavors are required to identify how experiential collaborative learning practices can be enhanced using Collaborative Virtual Environments (CVE), which can be described as "virtual worlds shared by participants across a computer network" and populated 3-D spaces that support collaborative learning, work, and social play (Benford et al., 2001). Synoptically, a computer-based simulated environment provides different features to create an online presence that can replicate multi-user with real-world settings. Such technology enables social interaction through several communication channels (e.g., text, audio, graphical icons, visual gestures, and multisensory inputs), supporting coordination actions, and allowing cooperation scenarios by using shared applications to manipulate digital objects and track changes (Jarmon et al., 2009). For instance, team members can jointly look at, and interact with digital artifacts in a shared virtual world (Schroeder et al., 2006). Earlier studies on collaboration procedural dynamics using 3-D CVE identified potential features for enhancing peripheral awareness (Bentley et al., 1992). Nevertheless, a lack of in-depth research approaches (i.e., ethnography) evaluating changing scenarios represents a recurrent challenge to identify requirements, limitations, and opportunities for adapting collaboration mechanisms to individuals, groups and crowds.

With the advent of the new millennium, CVE presented a set of research challenges related to new kinds of human factors and needs, distributed architectures, scalability and interest management (Benford et al., 2001), taking lessons from Computer-Supported Cooperative Work (CSCW), 2D interfaces, and anthropological research. However, research needs are constantly changing and it becomes necessary to understand the current working and learning activities in 3-D virtual environments. In this perspective, scientific literature can be a basis to identify a research agenda partially aware of technical innovations.

This study presents a meta-analysis of three-dimensional CVE focused on 35 publications (from journals, conference proceedings, and technical reports), supported by a Systematic Literature Review (SLR) adopting the guidelines provided by Kitchenham et al. (2004; 2009), Brereton et al. (2007), Unterkalmsteiner et al. (2011), and Stapić et al. (2012) to measure the current research possibilities. Bibliometrics (Price, 1963) is also applied as a method for measuring/analyzing scientific and technological literature. The contribution of this study is mainly established on the identification of the

state of research of a little portion of 3-D CVE bibliography bringing context to new researchers that are taking the first steps in this field.

Section 2 presents some background of virtual worlds and its applicability for several purposes. Section 3 explains the method, selection criteria and sample dimensions. Section 4 presents a bibliometric perspective of the sample analyzed in this paper to measure literature characteristics. Section 5 shows codified evidences from review identifying research gaps in 3-D CVE and discussing their implications. Finally, some remarks are summarized and discussed in section 6 based on the evidences extracted from the meta-analysis.

2. Entering the 'Cave': A brief Exploration of Three-dimensional CVE in a Social Era

Historically, CVE have been around since the early 90s, and some even before as 'hardware-only systems' (Joslin et al., 2004). These systems included technical improvements such as simulators, stereoscope, 'cinerama', head-mounted displays and trackers (Grady, 1998). Some topics studied in the first decades included location and time dependencies, reality *vs*. virtuality, anonymity *vs*. true identity, human *vs*. technological factors, level and scale of immersion, play *vs*. work, and presence *vs*. telepresence. Jäkälä & Pekkola (2007) argued that the research efforts on virtual worlds have transited from "considering them as tools to examining their use, from technology engineering to social engineering". While the focus relapsed on the technological aspects of 3-D CVE, there has been a need to understanding social interaction comparing the magnitude of co-presence (Bailenson & Yee, 2008). A key purpose of "social virtual worlds" consists in the co-construction of a shared meaning through object handling, and communication with different people within a world (Damer, 2008). In a vast comparison between game- and social-oriented virtual worlds, Stangl et al. (2012) summarizes their success factors from scientific studies, pointing the support for a critical mass of residents as one of the several success factors attracting users.

Metaverses can be conceptualized as 'immersive' three-dimensional virtual worlds within which people can interact with software agents "using the metaphor of the real world but without its physical limitations" (Davis et al., 2009). The development of digital ecologies has been marked by media spaces, CVE, mixed reality and hybrid ecologies which combine the mixed reality with ubiquitous computing "to bridge the physical-digital divide" (Crabtree & Rodden, 2008). In this sense, 3-D CVE can be described as collaboration ecosystems that minimize the risk of complex tasks through simulation features.

A notable portion of the literature studies suggests that 3-D CVE can be well suited for experiential learning activities (Jarmon et al., 2009), military operations and tactics, and strategies that require the latest innovations employing sophisticated technologies to prepare troops for real combat scenarios (Pierzchała et al., 2011), training processes in the context of mechanical maintenance tasks executed into the military hangars (Fonseca et al., 2011), and healthcare related approaches such as medical learning (Wiecha et al., 2010), dentistry (Phillips & Berge, 2009), and cardiopulmonary resuscitation (Creutzfeldt et al., 2010).

In the context of higher education, researchers have been focused on the identification of requirements and potential benefits of project-based instruction and collaboration. In particular, researchers have found opportunities associated with social interaction and collaborative learning,

increased sense of shared presence, lowered social anxiety, and partially liquefied social boundaries. Specifically, the Collaborative Learning Environment with Virtual Reality (CLEV-R) was developed to enhance the afore-mentioned aspects (Jarmon et al., 2009). Benefits in the use of simulation tasks in this kind of 3-D virtual environments range from cost saving to efficiency and security, and the amplification of sociability and scalability (Grimstead et al., 2005) can be far greater comparing with collaborative multi-user enabling systems.

Research in the K-12 and higher education suggests that interactions in three-dimensional CVE can stimulate users and produce conceptual understandings of the main subject matter (Jonassen, 2004), and the characteristics of this kind of virtual environments may promote collaboration to make the work more dynamic and engaging (Reeves et al., 2008). 3-D CVE have potential to support crowded online settings where hundreds of participants can reach social engagement by dynamically forming subgroups (Schneider at al. 2012), but more studies are needed in this research direction.

Virtual interpersonal touch appears as a phenomenon in which people can interact synchronously via haptic devices with a virtual environment. However, psychological effects related to the haptic communication need research to explore this issue. The addition of a haptic tool in 3-D CVE where users can touch each other may increase co-presence (Bailenson & Yee, 2008) by introducing a different 'mode of immersion' that can enhance spatial interaction between participants and objects.

In order to meet these evidences with an integrated view, a systematic literature review process gives a holistic perspective of bibliographical production in the 3-D CVE domain, measuring bibliometrics from the scientific papers, unsolved gaps that claim for further research, and semantic metadata that can complement results with probabilistic correlations.

3. Method

A representative sample of CVE literature is studied using an evidence-based methodology (Kitchenham et al., 2009) to provide a synthesis of literature reviews, taxonomy-based studies, and other classification approaches related with 3-D CVE. This research proposal relies on the identified need for recurring systematic studies to measure the evolution of topics, gaps, and opportunities for research in this domain. SLR is adopted as a method established in multiple domains (e.g., economics, software engineering, and healthcare) to collect and review research results from other studies using a pre-defined set of search terms. The purpose of this paper is to identify a research agenda for 3-D CVE aware of its current status and needs. Specifically, journal papers, conference proceedings, and technical reports representing a literature review, research agenda, or classification approach are distillated.

3.1 Research Questions

The formulation of Research Questions (RQs) respected a reflection process, stimulated by reading scientific papers in the field of 3-D CVE using the Google Scholar's advanced search to collect bibliographical data. The central question established in this paper relies on the definition of potential evidences about research gaps recognized in bibliography, leading to the following RQs:

> **RQ1:** *What contributions can be provided by a systematic review about three-dimensional CVE for learning settings?*

RQ2*: What are the unsolved gaps in 3-D CVE taking into account the existing literature reviews, taxonomic schemes, meta-analyses, and research agendas?*

RQ3*: How to validate the achieved results and construct a reliable research agenda for three-dimensional CVE?*

In order to answer these questions, this study is centered in a review of citable papers and technical reports to trace an integrated and updated research agenda for 3-D CVE for learning purposes. Meta-theoretic dimensions are analyzed under different perspectives, and an initial portrait of some of the main findings in these cross-sectional domains is the basis for leveraging this meta-analytic study. Quantitative indicators are also explored to correlate patterns of analysis and improve the consistency of this approach.

3.2   Search Process

According to McGowan & Sampson (2005), systematic reviews and meta-analyses have a great importance in providing reliable answers by involving a representative set of available research evidence to be analyzed and interpreted. Although SLR is increasingly used in software engineering, "this is not a trivial task and can be time consuming and fault-prone" (Hamad & Salim, 2014). Our review aims at identifying evidences, selecting and classifying studies for possible inclusion, synthetizing results, and interpreting findings. To validate this approach, we were involved in a bibliographic retrieval process, organizing a specific amount of data and subsequent documentation, and restructuring the findings in a context of research agenda. The necessity for a systematic review of 3-D CVE relies on the summarization of existing data in literature, refining hypotheses and estimating sample dimensions to define a research agenda (Cook et al., 1997).

Table 1 represents an overview of the search criteria (C) adopted in the presented meta-analysis, establishing a set of keywords introduced in Google Scholar's advanced search to show a bibliometric perspective about scientific research in virtual worlds with emphasis on collaborative learning. However, this is done indirectly since the main search was focused on the generic classification of 3-D CVE and their research gaps and opportunities.

Table 1: Characteristics of the search process

Keywords and correlated terms	Search index	Criteria
K1: Collaborative Virtual Environments K2: CVE K3: Virtual Worlds 'AND' CT1: Systematic review CT2: Taxonomy CT3: Classification scheme	Google Scholar's advanced search to filter papers by citation number and subject matter	C1: Journal papers, conference proceedings, and technical reports denoting research gaps and possibilities for 3-D CVE C2: Systematic reviews, historical approaches, taxonomies, research agendas and classification models intended to classify virtual worlds

In the first stage, keywords (K) and correlated terms (CT) were introduced to retrieve a total number of 136 studies in accordance to bibliometric indicators (i.e., total number of citations) provided by Google Scholar's citation index. This process was complemented by a snowball sampling approach to identify potential related studies from references. The retrieved papers were reviewed according to the

following sequence: i) keywords and general topic (defined from title), author(s) name, affiliation, country and additional identification data, ii) abstract, iii) full reading to identify possibilities and gaps and create an opening research agenda, and iv) bibliometric indicators (e.g., number of citations, topics, and countries).

3.3   Inclusion and Exclusion Criteria

The sample of the present study is a result of an inclusion/exclusion process based on the guidelines of Kitchenham et al. (2004; 2009), Brereton et al. (2007), Unterkalmsteiner et al. (2011), and Stapić et al. (2012), which show similarities in the procedural context. Initially, a total of 136 papers and technical reports were retrieved taking into account the total number of search terms described in Table 1. In the next phase, three duplicated papers were removed. The lack of quantifiable metadata for two studies was also an exclusion criterion. Subsequently, a total of 46 papers were removed due to the inadequacy of their subjects for a meta-analysis focused on 3-D CVE and their unsolved gaps. Finally, a set of 50 papers were not analyzed deeply because they do not fit the second criteria (C2) represented in Table 1. The remaining sample is constituted by a set of 35 publications associated with 3-D CVE representing an identifiable set of research challenges and possibilities. From this analytical corpus, a wide range of studies related with learning (e.g., K-12, higher education) were identified.

A review of the resulting publications was made according to bibliometric dimensions such as demographic and citation data. Table 2 represents a basis for a research agenda, partially aware of 3-D CVE requirements and shows the properties identified with the review process, structured by reference data, country of author's affiliation, publication venue, citations, method, subject, and Research Possibilities (RP) identified through content analysis. The most cited paper had 313 citations, and the general number of citations per paper is relatively reduced in this specific domain.

Table 2: Sample dimensions retrieved from literature

Author(s) and year	Country of author's affiliation	Publication venue	Total citations [1]	Method	Subject(s)	Research possibilities
Inman et al. (2010)	USA	Journal of Interactive Online Learning	20	Qualitative	Virtual Worlds, Education	[RP1]
Hew & Cheung (2010)	Singapore	British Journal of Educational Technology	65	Qualitative	Virtual Worlds, Education	[RP2]
Mikropoulos & Natsis (2011)	Greece	Computers & Education	33	Qualitative	Interactive Learning Environments, Education	[RP3]
Stanney et al. (1998)	USA	Presence	313	Qualitative	Human Factors, CVE	[RP4]
Parsons & Cobb (2011)	UK	European Journal of Special Needs Education	10	Qualitative	Autism Spectrum, Education, CVE	[RP5]
Bellani et al. (2011)	Italy	Epidemiology and Psychiatric Sciences	1	Qualitative	Autism Spectrum, CVE	[RP6]
Dalgarno et al. (2010)	Australia, USA	Australasian Journal of Educational Technology	14	Mixed Method	Virtual Worlds, Education	[RP7]
Zhou et al. (2008)	Singapore, New Zealand	IEEE International Symposium on Mixed Augmented Reality	132	Qualitative	Augmented Reality	[RP8]
Wright & Madey (2009)	USA	International Journal of Virtual Reality	6	Qualitative	CVE	[RP9]
Grimstead et al. (2005)	UK	IEEE International Symposium on Distributed Simulation and Real-Time Applications	28	Mixed Method	Collaborative Visualization Systems	[RP10]
Messinger et al. (2009a)	Canada, USA	Decision Support Systems	118	Mixed Method	Virtual Worlds, Business, Education	[RP11]
Messinger et al. (2009b)	Canada	Journal of Virtual Worlds Research	37	Qualitative	Virtual Worlds, Education, Business	[RP12]
Jäkälä & Pekkola (2007)	Finland	The DATA BASE for Advances in Information Systems	23	Qualitative	Virtual Worlds	[RP13]
Schmeil & Eppler (2008)	Switzerland	Journal of Universal Computer Science	21	Qualitative	CVE, Education	[RP14]
Olivier & Pinkwart (2007)	Germany	IfI Technical Report Series	1	Qualitative	CVE	[RP15]

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[1] Bibliometric indicators retrieved from Google Scholar's citation index in October 2012.

Author(s) and year	Country of author's affiliation	Publication venue	Total citations [1]	Method	Subject(s)	Research possibilities
Baladi et al. (2008)	USA	International Journal on Interactive Design and Manufacturing	3	Qualitative	CVE, Collaborative Design	[RP16]
Schmeil & Eppler (2010)	Switzerland	Facets of Virtual Environments	6	Qualitative	CVE	[RP17]
Otto et al. (2006)	UK	Virtual Reality Continuum and Its Applications	33	Qualitative	CVE	[RP18]
de Freitas (2008)	UK	JISC e-Learning Programme Report	85	Mixed Method	CVE, Education	[RP19]
Duncan et al. (2012)	Scotland, China	British Journal of Educational Technology	4	Mixed Method	Virtual Worlds, Education	[RP20]
Mennecke et al. (2011)	USA	Decision Sciences	8	Mixed Method	Virtual Worlds	[RP21]
Jarmon et al. (2009)	USA	Computers & Education	124	Qualitative	Virtual Worlds, Education	[RP22]
Bailenson & Yee (2008)	USA	Multimedia Tools and Applications	26	Mixed Method	CVE	[RP23]
Salmon (2009)	UK	British Journal of Educational Technology	75	Qualitative	Virtual Worlds, Education	[RP24]
Benford et al. (2001)	UK	Communications of the ACM	233	Qualitative	CVE	[RP25]
Davis et al. (2009)	USA	Journal of the Association for Information Systems	81	Qualitative	Virtual Worlds	[RP26]
Brown et al. (2011)	Australia	Business Process Management Journal	9	Qualitative	Virtual Worlds, Business	[RP27]
Joslin et al. (2004)	Switzerland	IEEE Communications Magazine	42	Mixed Method	CVE	[RP28]
Crabtree & Rodden (2008)	UK	Personal and Ubiquitous Computing	36	Qualitative	CVE, Ubiquitous Computing	[RP29]
Prasolova-Førland (2008)	Norway	Computers in Human Behavior	22	Qualitative	CVE, Education	[RP30]
Hasler et al. (2009)	Switzerland	International Conference on Human-Computer Interaction	6	Qualitative	CVE	[RP31]
Pinkwart & Olivier (2009)	Germany	Electronic Markets	4	Qualitative	CVE	[RP32]
Montoya et al. (2011)	USA	Decision Sciences	12	Mixed Method	CVE	[RP33]
Damer (2008)	USA	Journal of Virtual Worlds Research	21	Qualitative	Virtual Worlds	[RP34]
Wallace (2009)	USA	The International Journal of Technology, Knowledge and Society	0	Mixed Method	Virtual Worlds, Education	[RP35]

4. Bibliometric Indicators of 3-D CVE Research Production

In the review scheme presented in Table 2, predominance indicators are demonstrated for qualitative research studies followed by a mixed method (qualitative and quantitative). Nevertheless, content analysis can be error prone due to the inherent human interpretation complexity. Limitations can be also identified in the restrictiveness of the sample, which may not represent a large portion of the current gaps and challenges of research in 3-D virtual environments taking into consideration the learning and working requirements.

The distinction criterion between CVE and virtual worlds adopted in this research is two-fold. Considering a CSCW viewpoint, CVE "represent a technology that may support some aspects of social interaction not readily accommodate by technologies such as audio and video conferencing and shared desktop applications" (Benford et al., 2001), which encourage peripheral awareness in the content sharing and artifact production processes (Bentley et al., 1992). Virtual worlds can be also understood as 3-D virtual environments incorporating multi-use and immersive presence, inhabited by avatars, and providing a 'day-night context' (Morgado, 2009). In this perspective, collaboration support tools and projects such as Facebook, Moodle, and SLOODLE (Kemp & Livingstone, 2006) can be described as CVE providing learning features. Furthermore, Second Life and World of Warcraft are some of the most-known virtual worlds.

Bibliometrics can be established as a set of methods to analyze quantitatively scientific and technological literature (De Bellis, 2009). In this perspective, citation and content analysis are adopted as bibliometric methods to correlate a set of data aspects provided by literature. Figure 1 represents the

number of studies reviewed in this study by author's affiliation country. In this graphical representation, a greater scope from USA, UK and Switzerland was clearly identified. Although Australia does not show a major focus, it represents one of the countries with more studies in the current research scenario.
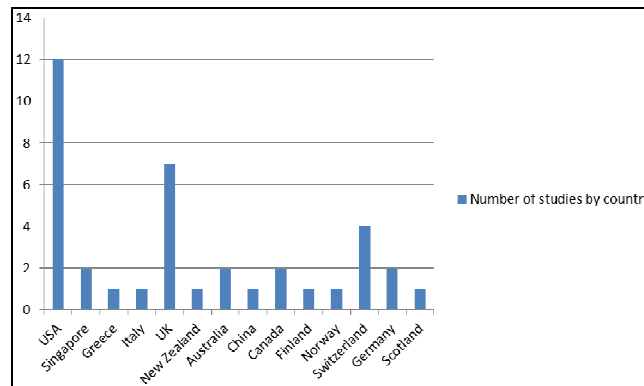

Figure 1: Number of reviewed studies by author's affiliation country (1998-2012)

The results can point to the study of collaboration through virtual worlds by North American researchers as a practice of their work purposes. The total number of fourteen countries is a notable indicator that brings an intercultural approach to the 3-D CVE research from several universities geographically distributed around different continents.

In the qualitative analysis represented in Figure 2, we can identify the related subjects for each study in a holistic way. CVE represent the main subject studied in this example, and it is followed by virtual worlds. Education is another field strongly examined in the recent years and in which there is a range of subareas to explore scientifically. Autism studies can be seen as a domain of notable importance to the future researches. Business remains as an interesting research field for CVE. Ubiquitous computing, Augmented Reality (AR), and collaborative design and visualization systems are other explored subjects. Finally, human factors are explored in a transversal way to the presented domains.
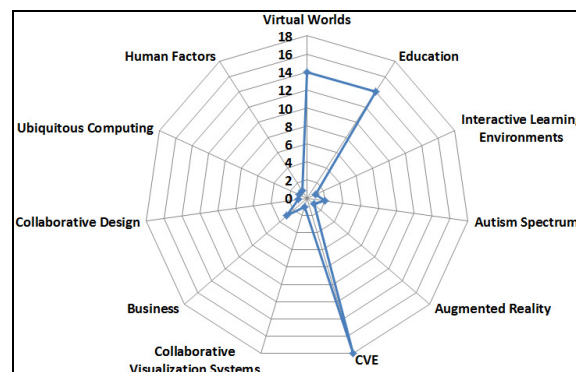

Figure 2: Subjects identified from review

5. Meta-Theoretic Review and Analysis of Three-Dimensional CVE

It is time to reposition the state of research in the field of 3-D CVE mobilizing researchers, students and practitioners in order to achieve new goals and improve their capabilities bridging complex pursuits in learning, healthcare, working, and leisure. The RP were coded through a reading process that

examines a set of unexplored topics, guidelines to raise awareness on learning, cooperative work and human factors claiming for compilation.

The research gaps and opportunities were achieved with a full-reading process, complemented with keyword search in the documents to obtain a new perspective about particular aspects. Some research notes were taken as a supplement to this bibliography-based analysis (e.g., sample size of review papers and non-covered quotes). In this venue, an overview of research gaps and possibilities for 3-D CVE (Table 3) is presented and supported by semantic evidences that can be suggestive for a more accurate meta-analysis with an extensive, granular and flexible framework portraying the current learning requirements of three-dimensional CVE.

Table 3: Codified data from review to identify research possibilities for 3-D CVE

Code	Evidence and description
RP1	E1: Researchers and educators need to collaborate developing more safe and secure environments for all students in K-12. E2: Little research is taking place in virtual worlds with K-12 education when compared with higher education.
RP2	E3: Androgyny, anthropomorphism, credibility, homophily, and selection criteria concerning avatars during an interaction can be a field for further exploration. E4: There is a need for more research examining the unique attributes/affordances of virtual worlds (e.g., collaboration features). E5: Future research is required to examine the influence of sociocultural factors and country contexts on the use of virtual worlds.
RP3	E6: Few studies have incorporated intuitive interactivity and settings that use immersive virtual environments reporting positive results on users' attitudes and learning outcomes. E7: Characteristics of virtual reality (e.g., immersion) and features such as the sense of presence (e.g., perceptual features, individual factors, content characteristics, and interpersonal, social and cultural contexts) seem to be essential for education and have not been studied extensively since 2003.
RP4	E8: Human performance efficiency, health and safety concerns, and social implications are some of the primary CVE challenges related with human factors.
RP5	E9: We still need to understand how to use the features of virtual reality to best support learning. E10: Questions about the nature of the representation itself remain unanswered. E11: There is much potential in the use of virtual reality technologies for autism and other healthcare contexts, which remains substantially under-explored in research terms.
RP6	E12: The use of virtual reality tools for habilitation in autism is therefore very promising and may help caretakers and educators to enhance the daily life social behaviors of autists. E13: Future research on virtual reality interventions should investigate how newly acquired skills are transferred to real world and whether virtual reality may impact on neural network sustaining social abilities.
RP7	E14: The compilation of an annotated bibliography of published research into, and evaluations of, 3-D immersive virtual worlds in Australian and New Zealand higher education can provide a solid platform for further research that can be generalized to all countries. E15: There is a need for accurate pictures of the 'state of play', including current, past and planned tools at various institutions, so as to help direct research, development and use.
RP8	E16: Augmented reality technology creates opportunities for exploring new ways to interact between the physical and virtual world, which is a field for future interventions. E17: Three research paradigms (i.e., ubiquitous computing, tangible bits, and sociological reasoning to problems of interaction) can be studied to create new interaction techniques. E18: Projection-based displays can have an optimistic future.
RP9	E19: A possible line for further examination relies on the refinement of past surveys of technologies for building CVE with different and updated variables.
RP10	E20: Contributions can be suggestive with the expansion of the current publication spectrum in collaboration visualization research.
RP11	E21: Attitudes and purchase intentions should be further examined so that companies can make decisions on the investment in their presence into virtual worlds and the marketing strategies most appropriate for their products, including co-creation and collaboration with consumers.

Code	Evidence and description
RP12	E22: Understanding how standards of social behavior are evolving in virtual worlds comparing with the physical world is needed. E23: A recurrent examination is needed to evaluate the influence of behaviors and attitudes learned in virtual worlds on real-world settings. E24: Opinions are divided concerning regulation in virtual worlds, including social values and norms implied in the process as well as their influence on aspects such as creativity and productivity. E25: Factors such as the monetary system in virtual worlds, nature of the platform, and forms of interaction allowed (e.g., synchronous and asynchronous) should be taken into account to understand their influence on people's behavior, identifying how they differ in meeting people's information needs, stimulating social interaction, or engendering trust. E26: What types of services, products or courses are most suitable in virtual worlds? E27: How can virtual world platforms be used for virtual service delivery and Customer Relationship Management (CRM), electronic retailing, teaching, and libraries? E28: How should the appearance of an avatar sales agent or instructor be designed? E29: Are different platforms more or less conducive to self-governance? E30: For media placement, what are the demographics, psychographics, geographic characteristics, membership sizes, and participation levels of various virtual worlds? E31: Do virtual worlds influence consumers' self-concept? E32: Will virtual worlds support themselves with a single up-front fee, periodic subscription payments, advertising, pay-as-you-go extras, or sales of ancillary products?
RP13	E33: Frameworks for studying and classifying individual users, virtual worlds, collaboration mechanisms and their relations should be proposed in a systematic way. E34: Relevant themes and research items in virtual worlds can be identified by using qualitative methods such as Grounded Theory.
RP14	E35: Additional patterns, different classification approaches, and well-grounded guidelines are required to establish effective experiences in virtual environments. E36: The current classification models are subject for on-going revisions, and scientific proof is still to be developed to help researchers, designers and practitioners to assess a 3-D collaboration and learning scenario in terms of its scope and benefits. E37: Future work could include experimental comparisons of collaboration tasks in three-dimensional CVE against corresponding tasks in text-based CVE and real-life collaboration settings. E38: To go deeper into collaboration, investigating the question of which theories help to explain 3-D interaction for collaboration and learning would be useful (e.g., the actor-network theory, Gibson's theory of affordances, and the cognitive scaffolding theory may be applied to 3-D environments). E39: So far it is unclear what enhancements are needed to make a CVE a really useful environment for serious distributed collaborations.
RP15	E40: Some research is still needed to fully understand the strengths and weaknesses of avatar representation in 3-D worlds in CSCW settings. E31: Possible research topics to explore are: i) workplace adoption, which depends on how easy and useful do people perceive the CVE, ii) success factors related with the increased interactions, positive self-awareness, social bonds (trust), or other undiscovered factors, and iii) usefulness of design elements as 'building blocks' to improve productivity in CSCW settings.
RP16	E32: Current taxonomies and other classification approaches should be refined and expanded in accordance with the new issues that are continuously discovered.
RP17	E33: More frameworks are needed to provide indications about the possible value added by collaboration patterns in virtual environments. E34: Further research is required concerning the use of controlled on-line experiments and in-situ participatory observation within organizations.
RP18	E35: Until recently, supporting closely-coupled collaboration between remote people was considered to be very difficult to achieve and little is known about the influences of different factors on such collaboration. E36: Many issues still need to be addressed regarding effective haptic implementations for immersive projection technology, as well as the importance of gaze, facial expressions and body postures during concurrent object interaction.
RP19	E37: It will be interesting to see how the license-fee based worlds will survive against the open source ones. E38: The tension between participation, learner control, educational standards and quality assurance may provide a framework for ongoing work in this space, and accurate benchmarking metrics for evaluation and validation are still a primary goal. E39: In the future, it is envisaged that multiplayer role play games and mirror worlds will also offer real opportunities for learning. E40: A commitment towards participatory approaches at all levels of engagement ensuring that the basic levels of education are maintained for future generations seems a central requirement for future development. E41: Forthcoming functionalities may also include the ability for users to create their own content, using tools such as Sketchup and 3ds Max.
RP20	E42: Appropriate educational activities, suitable learning environments, correct supporting technologies, revised learning theories, and experimental and verifiable evaluation practices are some fields of potential research and development for all population groups. E43: There is a need for both finely grained categorical work and holistic approaches to research and practice in virtual education. E44: More fine-grained research surveys are required to elicit trends and advances in this fast-moving field.
RP21	E45: Current classifications are subject to on-going revisions, and future research should focus on examining research models to determine their validity, particularly for organizational applications such as product sales, organizational meetings, or informational briefings.
RP22	E46: Future research would benefit from gathering data about the students' levels concerning technical abilities in virtual worlds prior to the educational activity. E47: While online 3-D virtual worlds are expected to have a large impact on teaching and learning in the near future, understanding their instructional use is still limited. E48: Experiential learning opportunities can be vastly expanded with the use of virtual worlds. E49: Some limitations include the representation of a single case study, one graduate course and semester in length, and few graduate students from different academic disciplines. E50: More research is needed to understand how experiential project-based collaborative activity may be applied in other instructional contexts using virtual worlds.

Code	Evidence and description
RP23	E51: It would be interesting to study the effects of being touched in a virtual environment. While previous studies have explored mutual force-feedback, more research is required to examine whether an agent that touched other would be perceived as more likeable in the same way that waiters get tipped more when they touch their customers. E52: A task using avatars of different skin tones or ethnicities might reveal user's attitudes towards different racial groups.
RP24	E53: At present, Second Life offers the most powerful object creation toolset of any 3-D MUVE, and we need to contemplate many possible futures, engage in dialogue and undertake evaluation with different stakeholders about available choices. E54: Awareness of teachers' visions about the potential of virtual worlds (especially in the teaching of history and science) is required. E55: The integration with other learning technologies is a prospect to create effective 3-D virtual classrooms. E56: It is needed to understand how to transfer pedagogical concepts from other electronic environments to frame group development and group working. E57: The creation of realistic environments for practice should be customized. E58: Predictions of interest from commerce and industry are required for skills development.
RP25	E59: Scalability, interest management, and distributed architectures are challenges facing CVE, which have been incorporating lessons from 2-D interfaces and CSCW as well as new kinds of human factors. E60: The ever-expanding variety of multiplayer games and simulators demonstrates the potential of CVE in leisure and entertainment. E61: Ubiquitous, mobile, and wearable computing promises an universal and continual access to digital information. E62: A future research challenge concerns the relationship between the shared digital world, manifested through CVE, and a shared physical world enhanced with digital data.
RP26	E63: A research gap that needs to be filled relies on understanding how metaverses are different from traditional virtual collaboration and what theories are relevant for enhancing understanding of behavior, management, and technology phenomena in this environment. E64: It is important to further investigate how teams balance in-world and out-world processes, and what tasks are amenable to metaverse technology capabilities.
RP27	E65: The emergent themes of intuitiveness ease of application, soundness, usefulness, user acceptance, and enhanced knowledge sharing ability provide interesting conjectures that could be tested in further, more controlled, empirical research. E66: Easy to use computer-supported networked collaborative process modeling is an emerging challenge for the process modeling community. E67: Further extensions will be necessary to ensure scalability to larger and more complex collaboration process scenarios. E68: There is a need for usability analysis to be applied in modeling interactions in order to improve their affordance for collaborative process tasks.
RP28	E69: Most systems address forms to provide basic CVE platforms to users so that they can expand and develop more complex interaction methods addressed mainly by the use of component/plugin-based architectures (i.e., modular systems), and how to increase overall usage and make CVE platforms a standard rather than a specialty through the use of Java applications, PC-based software, and Web interfaces.
RP29	E70: Understanding the nature of collaboration-based interaction within digital ecologies has been a longstanding concern within design. E71: The emergence of a new class of interactive environments that spans the physical-digital divide warrants attention as computing moves away to disappear into the fabric of everyday life. E72: Examining how novel interaction mechanisms are articulated across multiple physical and digital ecologies is essential to understanding the collaborative character of emerging physical-digital environments and, thereby, of informing design.
RP30	E73: An important issue to consider during an analysis of CVE systems is to what extent other factors than the virtual place design influence their suitability in a concrete educational situation. E74: How should three-dimensional educational CVE be designed to suit different educational purposes? E75: What place metaphors are typically used? E76: Which design features are beneficial and which are not? E77: How could the virtual place design in such worlds be analyzed in a systematic way?
RP31	E78: A factor that has often been neglected in virtual team research is the physical environment from which team members access the virtual environment. E79: A possible research agenda can be focused on behavioral indicators of high- and low-performing teams, sociability factors, and usability toward a theoretical foundation on collaboration in 3-D CVE. E80: An automated behavioral tracking approach can be an important step towards the systematic analysis of group interaction processes.
RP32	E81: A future question relies on the possible classes of group work and project-based learning that can be enhanced through CVE. E82: Where do the rich interaction options that CVE offer actually make a difference in practice? E83: Recognizing gestures and facial expressions of the user and projecting them into the virtual world through the avatar needs to be advanced, and the full potential of this interaction technique needs to be explored through ongoing CSCW research. E84: The system requirements of many existing CVE (especially the non-gaming ones) are still beyond the standard office PC. E85: Beyond basic HCI-related research and technological advancement, an open issue is concerned with the adoption of CVE in organizations. E86: It is not clear what needs to be done for CVE to make inroads into the everyday work practices of users, probably one of the most crucial aspects to deal with it is privacy. E87: There is a lack of systematic empirical research investigating the risks and chances of new options offered by CVE technology for collaborative work and learning contexts.

Code	Evidence and description
RP33	E88: Given the social relational affordances offered by 3-D CVE, future research should examine the content of communications and the relationship with performance, for example, team transcripts could be content coded to reveal the proportion of communications devoted to task-related interactions (conveying ideas and decision making) and social/relational exchanges. E89: Recent attention has turned to inter- and intra-organizational uses including collaborative virtual teamwork. E90: There is a need for systematic and foundational research that examines the impact of 3-D CVE on team behaviors and ultimately performance-related outcomes. E91: Further research is needed to gain a deeper understanding of the relative importance of affordances on both team processes and outcomes, particularly as they may vary by 3-D platform. E92: There is a growing body of research on virtual teaming that examines how communication technology use is related with aspects of mediated team collaboration. E93: Future research is needed to explore the learning curve associated with a 3-D CVE, which can help managers to understand what start-up costs will be needed to support a virtual team into a 3-D platform. E94: Longitudinal research engaging real teams in the context of real projects is required. E95: Further empirical testing via both controlled experiments and field studies is necessary to gain a deeper understanding of these environments, what sets them apart, and how they can become valuable platforms for collaboration scenarios.
RP34	E96: With the second coming of the avatar/social virtual worlds medium, meetings and larger events (from interviews on stage to fashion shows) are a driving force behind the growth and attraction to live in-world. E97: A large community of object makers, builders and marketers is emerging, which can be monitored by researchers to trace a continuum of collaboration application fields.
RP35	E98: While focusing on affiliativeness and sociability is an interesting first step in the investigation of collaboration in virtual worlds for education, it is recommended that further research should be undertaken to examine other personality traits related with collaboration in virtual worlds between avatars of different ethnicities, species and other forms, where further studies could examine such facets of personality as emotional empathy, arousal and sensation seeking, affect and emotions. E99: In order to both understand and foster the sense of community, it is needed the development of positive social attitudes that participants in distance learning environments hold toward their classmates' avatars.

A set of challenges and fields for further examination can be analyzed into an integrated theoretical framework (Table 3) when the research gaps and possibilities for 3-D CVE are considered. Therefore, the obtained results and current gaps are aggregated, coded, and discussed considering their main conceptual categories identified from data analysis.

It is possible to identify collaboration on 3-D CVE as the first prominent field of research, where most of the 35 texts examined in this study's designated questions associated with collaboration as the main focus. Theories regarding unique attributes and affordances of virtual worlds help to explain three-dimensional interaction in collaborative learning settings. Some identified areas that need effective research are also collaboration patterns in 3-D virtual environments, collaboration between remote people, collaborative activity in distinct instructional contexts (e.g., training), differences between metaverses and traditional virtual collaboration tools, computer-mediated team collaboration, and massive-scale networked collaborative processes trough metaverses.

Another area that has been identified as priority, in terms of research, is related to integration, sharing and content creation in 3-D CVE. The major indicators and main topics that should deserve research efforts have been emphasized by allowing users to create their own content and enabling most powerful 3-D object creation features. Furthermore, integration with other learning technologies and scalability between distributed architectures, tend to support larger and more complex collaboration scenarios. Lessons from 2-D interfaces can be considered, and there is a need to develop more detailed interaction methods, characterizing the use of component/plugin-based architectures, and integrating more interaction mechanisms. Research endeavors are needed to assemble different educational purposes by presenting new 3-D CVE, and to develop content among communications and interpersonal ties, established from social interaction.

The third area that requires reliable research is related to avatars' relationships, representations, and "feelings". Interaction issues concerning avatars' behavior (androgyny, credibility, homophily, and

anthropomorphism) constitute a line of further examination by analyzing the publications included in this study. Additionally, natural representation (strengths and weaknesses) and appearance of the avatar; immersive projection technology's implementations (facial expressions, gaze, and body postures), and touch effects in a virtual environment, are also research issues identified. A great body of sociological approaches could be devoted to ethnic and racial concerns (e.g., avatar skin tones, species, ethnicities, and other forms), and further analyses that could examine facets of personality such as emotional empathy, arousal and sensation seeking, affect, and emotions of the collaboration between avatars in virtual worlds.

Finally, issues related to classification and educational models can have a relevant role on the future of 3-D CVE. There are some areas of potential research and development concerning the refinement of current taxonomies and other classification approaches comprising users, virtual worlds, collaboration mechanisms and relations, and educational or learning standards, activities, technologies and theories.

6. Concluding remarks

The research presented in this paper represents some gaps and possibilities of three-dimensional CVE within an open, meta-theoretic research framework. The analysis carried on in this paper allowed identifying some lines of research based on healthcare contexts, augmented reality, K-12 research, entertainment, security, cultural influence and immersion, marketing and financial concerns, mobile and multiplayer technologies, open-source platforms, gestures recognition, social behaviors, and physical interaction.

Holistically, this meta-theoretic approach shows that 3-D CVE find their place as alternative ecosystems to enhance learning and collaboration capabilities between humans and computerized residents and objects. Ubiquitous augmented reality has been arising as a line of further examination, and ubiquitous tracking is on the path for future exploration. In a technical domain, platforms such as Xj3D can suite building and deploying three-dimensional CVE where integration with CSCW application tools allows increasing user's self-awareness, facilitating interaction, coordination, and improving social bonds.

Nevertheless, limitations remain unfilled at a bibliometric level (e.g., restrictiveness in the sample size). Heuristics, methods, and interpretations of literature-based evidences are error prone and there is a need to reinforce the creation of meta-theoretic research agendas and frameworks aware of the social-technical requirements of virtual worlds and metaverses. In addition, this analysis needs future revisions and different perspectives on the current status of research in 3-D CVE to reinforce an updated research basis oriented to several disciplines and researchers interested in the study of these collaboration support ecosystems.

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