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

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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 (Pierzchala 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>
<thead>
<tr>
<th>Keywords and correlated terms</th>
<th>Search index</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1: Collaborative Virtual Environments K2: CVE K3: Virtual Worlds ‘AND’ CT1: Systematic review CT2: Taxonomy CT3: Classification scheme</td>
<td>Google Scholar’s advanced search to filter papers by citation number and subject matter</td>
<td>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</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Author(s) and year</th>
<th>Country of author’s affiliation</th>
<th>Publication venue</th>
<th>Total citations</th>
<th>Method</th>
<th>Subject(s)</th>
<th>Research possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inman et al. (2010)</td>
<td>USA</td>
<td>Journal of Interactive Online Learning</td>
<td>20</td>
<td>Qualitative</td>
<td>Virtual Worlds, Education</td>
<td>[RP1]</td>
</tr>
<tr>
<td>Mikropoulos &amp; Natsis (2011)</td>
<td>Greece</td>
<td>Computers &amp; Education</td>
<td>33</td>
<td>Qualitative</td>
<td>Interactive Learning Environments, Education</td>
<td>[RP3]</td>
</tr>
<tr>
<td>Storey et al. (1998)</td>
<td>USA</td>
<td>Presence</td>
<td>313</td>
<td>Qualitative</td>
<td>Human Factors, CVE</td>
<td>[RP4]</td>
</tr>
<tr>
<td>Bellani et al. (2011)</td>
<td>Italy</td>
<td>Epidemiology and Psychiatric Sciences</td>
<td>1</td>
<td>Qualitative</td>
<td>Autism Spectrum, CVE</td>
<td>[RP6]</td>
</tr>
<tr>
<td>Wright &amp; Madey (2009)</td>
<td>USA</td>
<td>International Journal of Virtual Reality</td>
<td>6</td>
<td>Qualitative</td>
<td>CVE</td>
<td>[RP9]</td>
</tr>
</tbody>
</table>

1 Bibliometric indicators retrieved from Google Scholar’s citation index in October 2012.
### 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

<table>
<thead>
<tr>
<th>Author(s) and year</th>
<th>Country of author’s affiliation</th>
<th>Publication venue</th>
<th>Total citations</th>
<th>Method</th>
<th>Subject(s)</th>
<th>Research possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baladi et al. (2008)</td>
<td>USA</td>
<td>International Journal on Interactive Design and Manufacturing</td>
<td>3</td>
<td>Qualitative</td>
<td>CVE, Collaborative Design</td>
<td>[RP16]</td>
</tr>
<tr>
<td>Schmel &amp; Eppler (2010)</td>
<td>Switzerland</td>
<td>Facets of Virtual Environments</td>
<td>6</td>
<td>Qualitative</td>
<td>CVE</td>
<td>[RP17]</td>
</tr>
<tr>
<td>Otto et al. (2006)</td>
<td>UK</td>
<td>Virtual Reality Continuum and Its Applications</td>
<td>33</td>
<td>Qualitative</td>
<td>CVE</td>
<td>[RP18]</td>
</tr>
<tr>
<td>Mommeke et al. (2011)</td>
<td>USA</td>
<td>Decision Sciences</td>
<td>8</td>
<td>Mixed Method</td>
<td>Virtual Worlds</td>
<td>[RP21]</td>
</tr>
<tr>
<td>Jarmon et al. (2009)</td>
<td>USA</td>
<td>Computers &amp; Education</td>
<td>124</td>
<td>Qualitative</td>
<td>Virtual Worlds, Education</td>
<td>[RP22]</td>
</tr>
<tr>
<td>Salmon (2009)</td>
<td>UK</td>
<td>British Journal of Educational Technology</td>
<td>75</td>
<td>Qualitative</td>
<td>Virtual Worlds, Education</td>
<td>[RP24]</td>
</tr>
<tr>
<td>Benford et al. (2001)</td>
<td>UK</td>
<td>Communications of the ACM</td>
<td>233</td>
<td>Qualitative</td>
<td>CVE</td>
<td>[RP25]</td>
</tr>
<tr>
<td>Davis et al. (2009)</td>
<td>USA</td>
<td>Journal of the Association for Information Systems</td>
<td>81</td>
<td>Qualitative</td>
<td>Virtual Worlds</td>
<td>[RP26]</td>
</tr>
<tr>
<td>Jinlin et al. (2004)</td>
<td>Switzerland</td>
<td>IEEE Communications Magazine</td>
<td>42</td>
<td>Mixed Method</td>
<td>CVE</td>
<td>[RP28]</td>
</tr>
<tr>
<td>Crabtree &amp; Rodden (2008)</td>
<td>UK</td>
<td>Personal and Ubiquitous Computing</td>
<td>36</td>
<td>Qualitative</td>
<td>CVE, Ubiquitous Computing</td>
<td>[RP29]</td>
</tr>
<tr>
<td>Hasler et al. (2009)</td>
<td>Switzerland</td>
<td>International Conference on Human-Computer Interaction</td>
<td>6</td>
<td>Qualitative</td>
<td>CVE</td>
<td>[RP31]</td>
</tr>
<tr>
<td>Montoya et al. (2011)</td>
<td>USA</td>
<td>Decision Sciences</td>
<td>12</td>
<td>Mixed Method</td>
<td>CVE</td>
<td>[RP33]</td>
</tr>
<tr>
<td>Damer (2008)</td>
<td>USA</td>
<td>Journal of Virtual Worlds Research</td>
<td>21</td>
<td>Qualitative</td>
<td>Virtual Worlds</td>
<td>[RP34]</td>
</tr>
<tr>
<td>Wallace (2009)</td>
<td>USA</td>
<td>The International Journal of Technology, Knowledge and Society</td>
<td>0</td>
<td>Mixed Method</td>
<td>Virtual Worlds, Education</td>
<td>[RP35]</td>
</tr>
</tbody>
</table>
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.

![Number of reviewed studies by author’s affiliation country (1998-2012)](image)

**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.

![Subjects identified from review](image)

**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**

<table>
<thead>
<tr>
<th>Code</th>
<th>Evidence and description</th>
</tr>
</thead>
</table>
| 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. |
<p>| 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. |</p>
<table>
<thead>
<tr>
<th>Code</th>
<th>Evidence and description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP12</td>
<td>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 medium 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?</td>
</tr>
<tr>
<td>RP13</td>
<td>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.</td>
</tr>
<tr>
<td>RP14</td>
<td>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.</td>
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<td>RP15</td>
<td>E40: Some research is still needed to fully understand the strengths and weaknesses of avatar representation in 3-D worlds in CSCW settings. E41: 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.</td>
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<td>RP16</td>
<td>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 immersive projection technology, as well as the importance of gaze, facial expressions and body postures during concurrent object interaction.</td>
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<td>RP17</td>
<td>E43: Forthcoming functionalities may also include the ability for users to create their own content, using tools such as Sketchup and 3ds Max. E44: More fine-grained research surveys are required to elicit trends and advances in this fast-moving field.</td>
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<td>RP18</td>
<td>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.</td>
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<td>RP19</td>
<td>E46: Some research is still needed to fully understand the strengths and weaknesses of avatar representation in 3-D worlds in CSCW settings. E47: Understanding how standards of social behavior are evolving in virtual worlds comparing with the physical world is needed. E48: A recurrent examination is needed to evaluate the influence of behaviors and attitudes learned in virtual worlds on real-world settings. E49: 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. E50: 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. E51: What types of services, products or courses are most suitable in virtual worlds? E52: How can virtual world platforms be used for virtual service delivery and Customer Relationship Management (CRM), electronic retailing, teaching, and libraries? E53: How should the appearance of an avatar sales agent or instructor be designed? E54: Are different platforms more or less conducive to self-governance? E55: For medium placement, what are the demographics, psychographics, geographic characteristics, membership sizes, and participation levels of various virtual worlds? E56: Do virtual worlds influence consumers’ self-concept? E57: 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?</td>
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<td>RP21</td>
<td>E63: Frameworks for studying and classifying individual users, virtual worlds, collaboration mechanisms and their relations should be proposed in a systematic way. E64: Relevant themes and research items in virtual worlds can be identified by using qualitative methods such as Grounded Theory.</td>
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<td>RP22</td>
<td>E65: Additional patterns, different classification approaches, and well-grounded guidelines are required to establish effective experiences in virtual environments. E66: 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. E67: 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. E68: 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). E69: So far it is unclear what enhancements are needed to make a CVE a really useful environment for serious distributed collaborations.</td>
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<tr>
<td>Code</td>
<td>Evidence and description</td>
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| 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 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. |
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 mass-scale networked collaborative processes through 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 (androgyne, 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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References


Schmeil, A., & Eppler, M. J. (2010). Formalizing and promoting collaboration in 3D virtual environments - a blueprint for the creation of group interaction patterns. Proceedings of the First International Conference of Facets of Virtual Environments (FaVE ‘2009), (pp. 121-134), Berlin, Germany.


