

QUANTIFYING SITUATED LEARNING IN STUDIO-BASED EDUCATION:

Measurable effects of immersive VR on learning and teaching behaviours

RESEARCH QUESTIONS

The studio is the core setting in design education. This research aims to characterise and quantify two situated conceptual “educational spaces” generated during student-tutor interaction in high-end immersive VR-based design critiques. These two conceptual spaces are: (a) a teaching space that comprises behavioural actions of competencies; and (b) a learning space that comprises behavioural actions of design practice. Following situated learning theories (Vygotsky, 1978), actions of design practice comprise the learner’s knowledge and skills applied to practice design problem solving. Actions of competencies combine instructional strategies with tutor demonstration of design practice. Quantifying situated educational spaces will provide a solid foundation for rigorous learning assessment and the implementation of instructional strategies and high-end tools to support studio-based education, especially when using VR.

RQ1: How can we characterise, and measure situated learning and teaching spaces generated by the tutor and the student during student-tutor interactions in studio critiques?

RQ2: How do the characterisation and measurement of learning spaces relate to learning outcomes?

RQ3: What are the effects of immersive VR media on tutors’ and students’ teaching and learning spaces?

Why these questions are important

Design is one of the foundations for economic growth and well-being in any modern society. Design has to do with changing an existing situation to a desired one (Cross, 2006). The design field encompasses a wide range of domains, including architecture, construction, engineering (ACE), software design, game design, and product design. The studio, as a primary pedagogic vehicle for design professions plays a particularly important role in design education. Design has a significant impact on global economy. According to a recent design sector study (2023), the design industry in Europe has a market size of €21B and has experienced a 24% growth since 2020. Whilst in the US it contributes \$600B to the GDP (Figure 1. Zevin and Rubin, 2021). Furthermore, digital design has witnessed substantial growth, as reported by the UK's Design Economy (2022), hence the focus on VR.

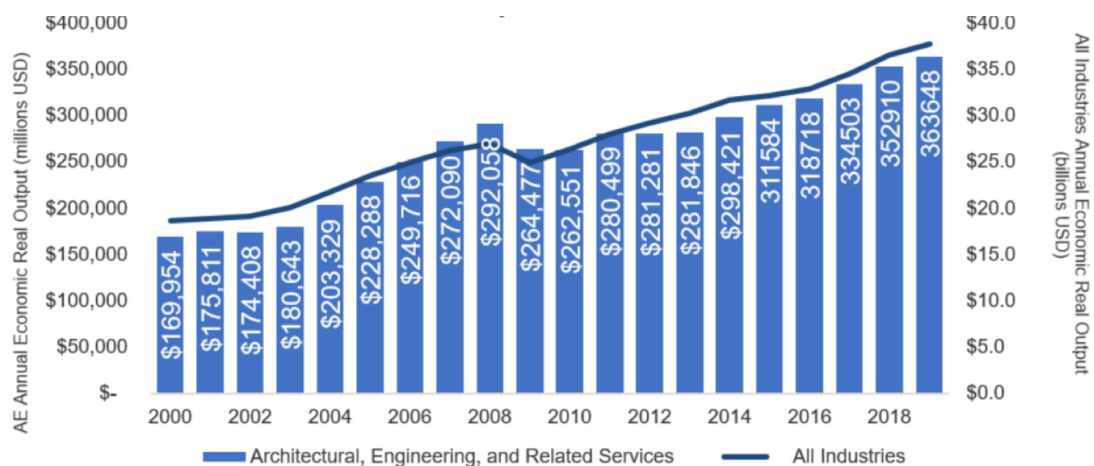


Figure 1. ACE’s effect on US economic output of industries during 2000-2019. (Zevin & Rubin, 2021)

Despite design's pivotal role in society, the education sector reports notable gaps in the capability to measure learning and teaching effectiveness within design studios (Geisinger, 2016; (Greiff & Kyllonen, 2016; Herde et al., 2016; Trede et al., 2020). Current methods can measure only a single type of task (Trede et al., 2020) which does not suit the multiple interrelated problems arising in design. Most common to design studios, formative and summative assessments provide qualitative assessments of the learning outcomes (Sawyer, 2017). These gaps have led to critical failures in providing explicit feedback on the skills gained or the ones that need further teaching support (Salama, 2015; Schweisfurth, 2015). As a consequence, implementing effective instructional strategies such as a learner-centric education (Bremner, Sakata and Cameron, 2022; Logeswaran et al., 2021; Olofson and Garnett, 2017; Schweisfurth, 2015) to overcome the studio's tutor-centric profile (Milovanovic & Gero, 2018; K. R. Sawyer, 2019) are restricted. Most studies aiming to provide explicit feedback base their assessments solely on learner's generation of design practices as evidence of learning. Consequently, such methods fail to adequately assess the way learning and teaching behaviours are applied to handle the design problem as an educational task, restricting the measurement of the cognitive learning level imposed or the interrelations between learner's engagement and the tutor's stimuli.

In addition, with the global shift in using immersive virtual reality (iVR) systems in many sectors (Slater & Sanchez-Vives, 2016), and in design practice in particular (Spaeth & Khali, 2018), it is essential to integrate such cutting-edge technology in design studios to ensure the gaining of relevant computational skills. iVRs have become a primary medium to interact and collaborate free of physical constraints. However, gaps in describing the cognitive behaviours generated during the exploration of immersive displays (Beck et al., 2020; Ummihusna & Zairul, 2021) limit the use of this technology as an educational setting. With the complex problems faced globally by the society (United Nations, n.d.), the need for rigorous methods to measure situated education like the studio, has been recognised. Calls are published by global organisations like UNESCO (2016) and GUNi, (2022) seeking explicit measurement approaches.

The significance of these gaps becomes even more crucial as studio-based education spreads to additional disciplines. Examples can be found in computer science (Polo et al., 2018), engineering (Bone et al., 2021) and others, mainly to the studio's support in gaining complex problem-solving skills and the pro-active use of computational tools, known as the 21st-century core skills (Griffin and Care, 2015; Miranda, et al., 2018).

LITERATURE REVIEW

The Design studio

Rooted in the *École des Beaux Arts* apprenticeship model and the Bauhaus school's encouragement of creativity (Cuff, 1991; Salama, 1995), the design studio serves as the principal setting for educating how to design. Drawing upon situated learning theories (Lave and Wenger, 1991; Vygotsky, 1978), learners and tutors in the studio interact in simulated design situations to solve design problems (Schön, 1985). Through this learning process, learners gain design knowledge by practicing design behaviours and by listening and imitating their tutors. Such interactions occur regularly during formative assessments, known as "critiques" or "crits" as well as during formal summative assessments, known as "reviews" where learners mid-term and final learning outcomes are assessed and graded (Oh et al., 2013). The process is accompanied with design representations, created to communicate information regarding the design artefact, or its parts (Schön & Wiggins, 1992). By stimulating discovery and progress (Ibid), representations play a significant role in design education.

Dealing with the wicked nature of design problems (Rittel & Webber, 1973), studio crits are complex and dynamic, requiring both tutor and student to handle a set of high-level open-ended, conflicting, and ever-changing requirements. Consequently, this demands high cognitive levels as indicated in Bloom's

Revised Taxonomy (BRT)(Kratwohl, 2002). While professional designers handle such challenges by breaking down problems into chunks and shifting to solutions, students' capacity to do so is limited, leading to inefficiencies or errors (Cross, 2004). Therefore, the tutor's role in framing an adequate cognitive level and stimulating progress becomes pivotal (van Diggelen et al., 2021).

The dialogic nature of student-tutor interaction during design crits leads to the co-construction of knowledge (Stahl et al., 2006), reflected through new or refined design solutions (or sub problems). Consequently, these factors bring notable risks for the interaction to be tutor-centric, as found in multiple studies (Milovanovic & Gero, 2018; K. R. Sawyer, 2019) and criticised over the years for preserving hidden hierarchies (Dutton, 1987; Webster, 2008), hindering learner participation and therefore critical thinking. Crits' current ambiguous feedback creates frustration in students' expectations (Albukhari, 2021; Yorgancıoğlu et al., 2022; Salama, 2015), that may hinder the student's engagement and responsibility for progress.

iVR Technology

iVR systems are a high-end technology that has seen substantial growth in various sectors, including situated education (Slater & Sanchez-Vives, 2016) and design practice (Spaeth & Khali, 2018). This concerns the systems' capacity to provide an authentic and interactive environment necessary for gaining implicit knowledge in situated learning (Fromm et al., 2021; Hamilton et al., 2021; Slater, 2017). iVRs enable learners and tutors to experience a sense of presence in a shared and surrounding digital display, facilitating interactions with 3D artefacts at a real scale (Slater et al., 2022; Slater & Wilbur, 1997). These characteristics make iVRs increasingly relevant in the design education domain that essentially handles non-existent situations.

In the design education domain, iVRs are found supportive for design studios (Rodriguez et al., 2018), with demonstrated advantages in increased student ideation (Boudhraa et al., 2019; Sopher, et al., 2022), interaction (Milovanovic & Gero, 2022), generation of design issues (Sopher, et al., 2022), learner engagement (Obeid & Demirkan, 2023) and tutor demonstration (Sopher & Dorta, 2023).

Notwithstanding these claimed benefits, these studies rely on occurrence of design practices as evidence of learning, neglecting behavioural actions of learning and teaching applied to handle the design problem. This restricts understanding iVRs' educational role in supporting an adequate cognitive level, critical thinking or an effective instructional strategy. Studies acknowledge these gaps, pointing to a need to track cognitive behaviours generated during the exploration of immersive displays (Beck et al., 2020; Ummihusna & Zairul, 2021). Addressing these shortcomings is crucial to investigate iVRs' role in situated education to allow their integration into design studios.

EXPECTED CONTRIBUTION. Quantifying learning and teaching in design studios

Formative and summative assessments play a critical role in studio education. However, these assessments regularly focus on the learning outcomes (De la Harpe et al., 2009; K. R. Sawyer, 2017), neglecting the design practices gained and the ones that necessitate further practice. Nor can such assessments provide a foundation for assessing teaching competencies. Widely used methods like the Function-behaviour-structure (FBS)(Gero, 1990; Gero & Kannengiesser, 2004), and Linkography (Goldschmidt, 2014), have shown to be efficient and reliable in measuring design behaviours performed by designers and students (Cross, 2001). However, designed to describe and measure the design process, they lack behavioural actions of learning and teaching applied to handle the design problem as an educational task. This limits the development of knowledge on how learning and teaching are structured and interrelate, or whether they apply a suitable cognitive level (in terms of Bloom's Revised Taxonomy).

Following the literature above, and different from former approaches, this research suggests

characterising student-tutor interactions during studio crits through two conceptual interconnected spaces relying on the behavioural actions that handle intended design practices and frame competencies: the learning space (L_s) and the teaching space (T_s), as depicted in **Figure 2**.

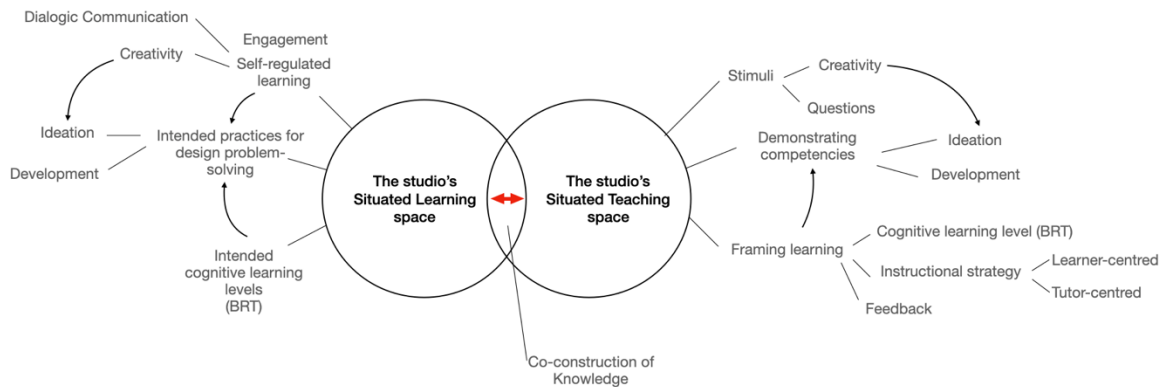


Figure 2. Learning and Teaching spaces generated during design studio crits.
Based on ATC21S (Griffin & Care, 2015)

Based on the 21st-skills described by Griffin and Care (2015), L_s comprises behavioural actions of cognitive levels, and self-regulated learning, applied to practices of design problem-solving. Accordingly, self-regulated learning has to do with the learner's engagement in being active during the learning process to achieve progress. This refers to the learner's part in leading a dialogic communication with the tutor and demonstrating creativity. In design crits, the learner's activity refers to design practices, needed to ideate and develop a design solution (Cross, 2006). T_s comprises behavioural actions that combine instructional strategies with cognitive level and stimuli to progress, applied to frame learning to encourage progress. The tutor can stimulate progress by raising questions, or by encouraging creativity. These behavioural actions are applied by the tutor as she demonstrates the competencies needed for problem-solving. In design, these include the active demonstration of ideation and development towards a design solution (Cross, 2006). Creativity is associated with divergence and convergence behaviours (Goel, 2014).

Characterising L_s and T_s with the components mentioned above, will enable quantifying these situated educational spaces. Results are expected to provide new knowledge on how studio-based education can be measured, significantly contributing to the research and education sectors by enabling custom-tailored teaching and skill improvement. Articulating the role played by iVRs on educational behaviours will enable the integration of this cutting-edge and increasingly used medium to support situated learning explicitly.

The originality and innovation of this contribution are found in providing a systematic method to characterise and measure studio-based learning and teaching performance. Understanding the complex relationship occurring during student-tutor interactions in studio crits can support the planning and application of desired teaching competencies to overcome tutor dominance and ambiguous feedback, leading to performance-based custom-tailored teaching. The proposed research can begin to enclose the gap in assessing situated learning and teaching, allowing comparative studies, and improving the gaining of the 21st century's skills in studio-based education, spread in many disciplines. This opens situated education's black box, **laying the foundation for predictive analytics** of learning and teaching behaviours and leading studio-based education to its next step for being a prominent factor in shaping 21st-century pedagogy.

HYPOTHESES

- **H1:** The size and structure of L_s and T_s will change throughout crit time.
- **H2:** L_s measures will correlate with learning outcomes assessments.

- **H3:** Using iVR in design crits will change *Ls* measures, compared to non-immersive media.
- **H4:** *Ls* and *Ts* generated in architecture crits is different than *Ls* and *Ts* generated in computer science crits.

OBJECTIVES

The objectives of the research are:

- **O1:** Characterise *Ls* and *Ts* components and their and interrelations (needed to support **H1**).
- **O2:** Measure *Ls* and *Ts* size, structure, and temporal changes (**H1**).
- **O3:** Measure the correlation of *Ls* with learning outcomes (**H2**).
- **O4:** Compare *Ls* generated in iVR and non-immersive media (**H3**).
- **O5:** Compare *Ls* in architecture and computer science studios (**H4**).

METHODOLOGY: Proposed methodology and why it was selected

This study brings an innovative approach to situated education domain, by providing explicit methods to measure educational teaching and learning spaces. It postulates that *Ls* and *Ts* comprise a set of behavioural teaching and learning actions applied to and responsible for the design practices and competencies generated to handle a design-problem as educational task. **Tables 1 and 2** describe *Ls* and *Ts* components and their interrelations to be measured in this study.

Table 1. Learning space (*Ls*) components and measurements methods

Behavioural learning actions	Design practices for design problem-solving	Measurements
Engagement, Self-regulated learning	Dialogic communication	<ul style="list-style-type: none"> • Ratio of the learner's and tutor's utterances • f Ratio of the learner's and tutor's first occurrence of design issues, using NLP algorithms. • Ratio of the student's design issues and transitions, coded with the FBS ontology
	Creativity	Shifts between divergence and convergence, using NLP algorithms
Cognitive learning level	Action verbs applied to design issues	Action verbs categorised into BRT six cognitive learning levels, using ChatGPT

Table 2. Teaching space (*Ts*) components and measurements methods

Behavioural teaching actions	Design competencies for design problem-solving	Measurements
Framing	Instructional strategy	Measured by the student's engagement
	Cognitive level	The tutor's introduction of new and higher cognitive levels compared to the student. This is measured by Action verbs, categorised into BRT six cognitive learning levels, using ChatGPT
	Feedback	<ul style="list-style-type: none"> • Sentiment analysis techniques. • The tutor transitions over the student issues • Number of questions, using ChatGPT
Stimuli	Questions	The tutor's number of questions, using NLP algorithms
	Creativity	Tutor's first occurrences and shift of divergence

		convergence
Demonstration	Generating design issues and transitions	First occurrence of tutor ideas, tutor transitions over the student issues

Behavioural actions of learning and teaching

Cognitive learning levels

The study will employ Bloom's Revised Taxonomy (BRT) (Krathwohl, 2002) as an analytic tool to determine the cognitive learning level applied by the student or framed by the tutor during design crits. BRT classifies action verbs (AV) into six cognitive learning levels. The levels are (from the lowest to the highest): *Remembering, understanding, applying, analysing, evaluating* and *creating*. BRT cognitive learning levels were shown to be effective in planning qualitative teaching sessions to be learner-centric (El-Sayary et al., 2016), defining learning objectives (Sobral, 2021) or assessing tutors' written questions (Das et al., 2022). The list of AVs provided by Das, et al., (2022) was employed to assess whether the cognitive level of questions in exact science exams meets the requirements of India's national school boards (Roy Chowdhury et al., 2023). Different than these studies, this project will be the first time that BRT will be used to examine crit interactions. This will determine whether the cognitive level framed by the tutor leads to a change in the student's level, or whether the interaction required a change in level, customised to meet the learner's level.

Design practice and design competencies:

The design behaviours generated during studio crit interactions will serve as evidence for learning and teaching, seen in the student's active practice and the tutor's demonstration. The study will employ several protocol analysis techniques (Cross et al., 1996) to track the occurrence and frequency of these behaviours:

Function Behaviour Structure (FBS) ontology: FBS ontology (Gero, 1990; Gero & Kannengiesser, 2004) provides a detailed description of the semantic information of design issues generated during a design session, referring to the form's intended purpose, structure, or expected and derived characteristics. Transitions between issues describe the considerations taken by the designer to develop the design towards a satisfactory solution (e.g., a transition from the form's structure to its expected behaviour). The ontology has been widely used widely used in studies across multiple domains (Gero & Jiang, 2014, 2016; Hay et al., 2020; Kan & Gero, 2009), including ones conducted by the PI (Sopher, et al., 2022; Sopher et al., 2023).

The first time an issue is introduced during a design session is a first occurrence (FO). It is considered a proxy of a new idea (Gero & Kan, 2016). It reflects a measure of divergence and creativity through FOs' frequency. The cumulative number of FOs generated across a design session is a temporal measure of this behaviour (Ibid). Recent studies by the PI employed the technique to measure iVR's effect on students' ideation (Sopher, Milovanovic, et al., 2022; Sopher & Gero, 2021) and the medium's temporal effect on this design behaviour in different crit phases (Sopher et al., 2023).

Methods

Based on protocol analysis for analysing design behaviours (Cross et al., 1996), the study will employ multiple methods to measure L_s and T_s components (Tables 1 and 2).

ChatGPT AI platform will be used to identify AVs and classify them automatically into BRT cognitive learning levels. This was tested successfully in pilot studies described in the following section.

In addition, NLP techniques will be employed to identify FOs automatically, based on previous studies (Sopher et al., 2022), and recently developed in collaboration with Casakin and Gero (research supported by the ISF). These techniques will be further developed to determine measures of the feedback given, and the frequency of tutor's questions. The study will also use sentiment analysis to calculate constructive criticism

values.

Learning outcome assessment:

The study will evaluate the learning outcomes prepared for mid-term and final reviews to determine their quality in meeting the expected learning requirements. This will be done by external reviewers who are professional tutors or guest professionals attending the reviews. Evaluations and *Ls* measures will be used to examine **H3**.

RESEARCH DESIGN

To achieve the objectives described above, the research will conduct comparative experiments in ecologically valid design studios. This will provide results that can be generalised and applied to real-life educational settings. The experiments will have two independent variables: (1) the technology used: iVR and non-immersive media; and (2) students and tutors. Learning and teaching behaviours and the practices and competencies generated during design crits will be the dependent variables. Student-tutor verbal interactions during design crits and reviews will be audio and video recorded and segmented by speaker (student and tutor) and time.

Figure 3 illustrates the research design.

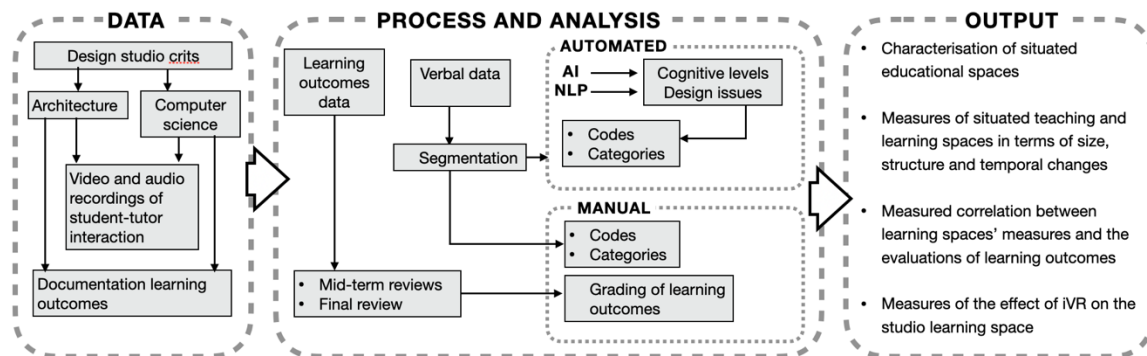


Figure 3. Research design

Experiments will use a convenience sample by monitoring ecologically valid studio crits taking place in the Architecture and Computer Science disciplines. The study will conduct several experiments to support the hypotheses.

Sample: The research sample will consist of 20 students from the school of Architecture, and 20 students from the department of Computer Science, at Ariel University or an equivalent institution. All students will be in their third or fourth year of undergraduate program, a learning stage where they have prior experience in operating computational tools, familiarity with studio-based education and design procedures.

Setting: The research will conduct a balanced comparative experiment, following a design studio that will use iVR and non-immersive media during design crits. Students will be given first the iVR or the non-immersive setting randomly. The iVR and non-immersive media will be the independent variables. Each student will have 2 crits. Non-immersive media, like sketching tools, models and desk computers, will be used in a common studio classroom. The iVR will be the Hyve-3D (Dorta, et al., 2016). Hyve-3D is a high-end hybrid system equipped with a 5-meter diameter of concave screen, allowing for up to 8 participants to have a shared view in a collocated space, or a remote view by using an equivalent system. Different than most iVR systems, the Hyve-3D allows a shared immersive view without assistive tools like headsets or 3D glasses. This allows users to interact naturally. This cutting-edge iVR allows for independent navigation in a real-scale view, 3D sketching, and moving imported digital artefacts using iPads. Former studies found it advantageous for studio-based education in product

design (Ayed & Dorta, 2021; Boudhraa et al., 2019; Dorta et al., 2016), and collaboration between students coming from product design, engineering, and ergonomics (Sopher & Dorta, 2022).

To support **H4**, the research will conduct a comparative experiment, following natural case studies of design studio course in architecture and in computer science, using the common studio classrooms.

Previous studies

The PI conducted multiple studies focusing on studio-based education and the effect of several iVR types on student-tutor design interactions. Among these, a recent study proposed a method to quantify learner-centric interaction, applied to a comparative natural case-study (Sopher et al., submitted). Multiple studies comparing student-tutor interaction measured student design practices accounting for FOs (Sopher & Gero, 2021), connections between concepts (Sopher et al., 2022), and the generation of design issues and transitions (Sopher et al., 2022) and their generation across crit phases (Sopher et al., 2023). Studies investigating iVRs' effect on learning outcomes developed a method to measure learner productivity (Sopher et al., 2017), divergence and convergence of concepts (Sopher et al., 2019) and the level of development (Sopher et al., 2018). Studies focussing on collaborative design using the Hyve-3D investigated student-tutor verbal interactions and outcomes generated and modified during the process (Sopher and Dorta, 2022, 2023). The methods utilized and developed, and the insights found in these studies demonstrate the PI's significant experience in the field, serving as a basis for accomplishing the research objectives.

Despite their contributions, since these studies rely on the occurrence of design practices and tutor's design competencies, they lack the capabilities to measure the behavioural teaching and learning actions applied to and framed by design practices and competencies during the learning process.

Pilot studies

The measurements and automated technique offered in this project were applied to two pilot cases. The PI analysed existing data using ChatGPT version 3.5. The results and their interpretation form a tangible example of the outcome that this study can bring with a statistical sample.

Case study 1

The first case study compared the interactions of one student and one tutor in an architecture crit that used a hybrid, room-sized iVR. Data was previously collected by the PI. ChatGPT version 3.5 was used to automatically identify AVs and classify them into BRT cognitive learning levels. Automating the process brings an innovative and efficient approach to protocol analyses which are often time consuming. This potentially allows for such assessments to become ubiquitous for both tutors and students.

This pilot experiment brings interesting results. Although the student and the tutor generated a similar number of AVs (Sixty-seven for the student and Eighty-eight for the tutor), they differed in the cognitive level (**Figure 4**). The student primarily used the third

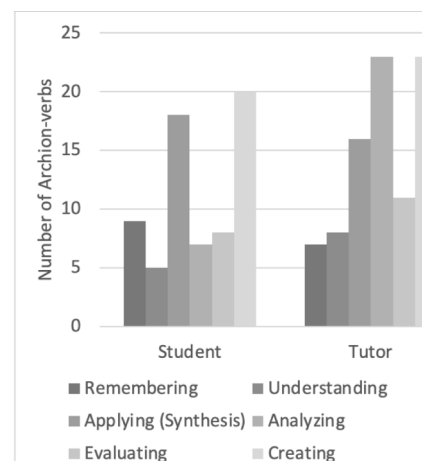


Figure 4. Distribution of Action-Verbs generated by the student and the tutor during an iVR crit, classified to cognitive learning levels.

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and sixth learning levels (*Applying* and *Creating*), whereas the tutor used the third, fourth, and sixth levels, framing the interaction with higher levels. More student AVs related to *Applying* level compared to the tutor's indicate a learner-centric interaction on this cognitive level.

Further analysis investigated whether the student's and the tutor's cognitive learning levels changed across crit time. **Figure 5** presents the distribution of AVs generated by the student and the tutor classified into cognitive learning levels during crit's early, mid, and final phases. Results exhibit large differences between the student and the tutor for each phase. The student had more AVs related to *Creating* and *Applying* levels during the crit's early phase. Comparatively, the tutor in this stage generated more *Analyzing* AVs to frame the interaction, while also using her prior knowledge, reflected through *Remembering* AVs. The second crit stage had increased tutor AVs in all learning levels (except *Remembering*), *Analyzing* and *Creating* in particular, compared to the student, showing a tutor-centric interaction. The third phase had a decrease in the student's *Creating* and *Remembering* levels and increased AVs related to *Understanding*, *Analyzing*, and *Evaluating*.

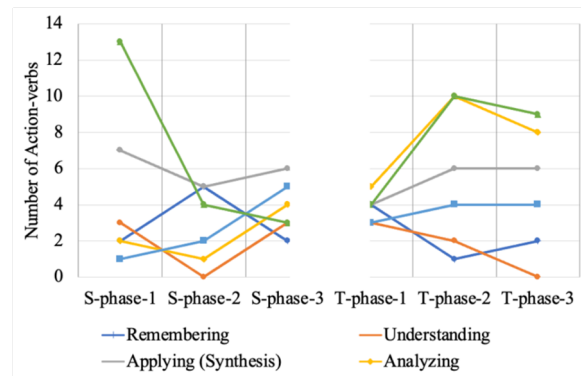


Figure 4. Distribution of Action-verbs generated by the student (S) and the tutor (T) during crit's phases.

Case study 2

This study compared the cognitive learning levels applied in student-tutor crit interactions in a STEM domain. Data was provided by Professor John S. Gero from a previous experiment, consisting the verbalisations of a single tutor and a single student. Three minutes of interaction yielded 130 segments. **Figure 6** presents the distribution of the tutor's and student's AVs classified to BRT cognitive learning levels. Results from this short analysis show a difference between the student and tutor. From the very beginning of the crit, the tutor frames learning using all cognitive levels while enhancing the fourth and fifth levels.

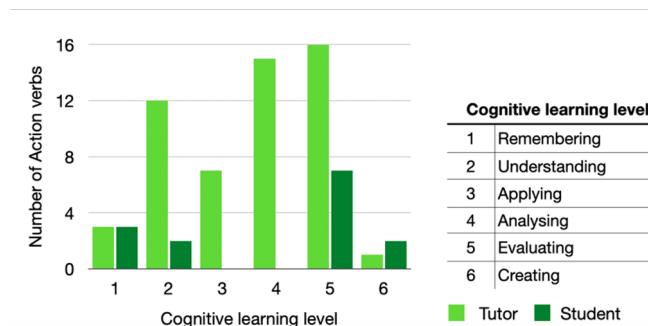


Figure 5. Distribution of cognitive learning levels generated by the tutor and the student during a design crit in the STEM domain.

PREFERRED EXPERTISE OF A GRANT REVIEWER

1. Design education
2. Design thinking
3. Education- Situated learning.

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