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Developing a Heatmap Rubric to Assess Meaningful Learning: A Meta-Analysis Grounded in the Interaction Equivalency Theorem

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ABSTRACT

In the evolving landscape of education, understanding how different modalities of course delivery impact student learning is crucial. Anderson's (2003) Interaction Equivalency Theorem (IET) provides a guideline for designing effective interactions in distance learning. Anderson's theorem states that deep and meaningful formal learning is supported as long as one of the three forms of interaction (student–teacher, student–student, or student–content) is at a high level. High levels of more than one interaction mode may provide a more satisfying educational experience, although these experiences may not be as cost- or time-effective. While Anderson's theorem was based on distance education, it can be extended to hybrid and traditional learning. The IET, as further discussed by Garrison (2017), emphasizes that a balance of student–content, student–student, and student–teacher interaction can lead to meaningful learning.

Keywords: Heatmap Rubric, Meaningful Learning, Interaction Equivalency Theorem, Three-way Interaction

INTRODUCTION

Understanding the Interaction Equivalency Theorem

The IET posits that meaningful learning occurs when a learner actively engages with content, peers, and instructors (Miyazoe & Anderson, 2010). According to Moore (1989), the three types of interaction are defined as follows:

- **Student–Content Interaction:** This involves students engaging with course materials, such as readings, videos, and assignments.
- **Student–Student Interaction:** This encompasses collaboration, discussion, and peer feedback among students, fostering a community of learners.
- **Student–Teacher Interaction:** This includes feedback, guidance, and support from instructors, which can greatly enhance the learning experience.

By assessing these interactions, educators can gain insights into how effectively a course delivery method facilitates meaningful learning. However, the IET lacks specific delineation of meaningful learning at the intersection of students' interaction types and course delivery modalities. We suggest developing a heatmap rubric to characterize different levels of this intersection and enable the identification of the highest level of meaningful learning.

Designing the Heatmap Rubric

The term *heatmap* was first trademarked in the early 1990s, when a software designer, Cormac Kinney, created a tool to graphically display real-time financial market information (Jurkonytė, 2023). The practice we now call heatmaps is thought to have originated in the 19^{th} century, where manual gray-scale shading was used to depict data patterns in matrices and tables.

The heatmap rubric proposed here serves as a visual representation of the levels of meaningful learning in a course. The following steps outline the creation process:

Step 1: Define Learning Outcomes

Establish clear, measurable learning outcomes that reflect meaningful learning. These outcomes should align with the course objectives and provide a foundation for assessment.

Step 2: Identify Course Delivery Modalities

Different course delivery modalities may include:

- **Face-to-Face:** Traditional classroom settings.
- **Blended Learning:** A mix of face-to-face and online instruction.

- **Fully Online:** Courses delivered entirely through digital platforms.

Step 3: Develop Interaction Metrics

Create specific metrics to measure each type of interaction. Possible metrics include the frequency of engagement (e.g., number of posts in a discussion forum), the quality of interactions (e.g., depth of responses), and the diversity of interactions (e.g., variety of sources used in student–content engagement).

***Step 4: Create the Heatmap Framework ***

Design a heatmap table that includes:

- **Horizontal Axis:** Course delivery modalities (face-to-face, blended, fully online).
- **Vertical Axis:** Types of interactions (student–content, student–student, student–teacher).

Each cell in the table represents the intensity or effectiveness of interaction for that modality and type. Use color coding to indicate levels of engagement ranging from low (e.g., red) to high (e.g., green).

Step 5: Collect Data

Gather data through surveys, learning analytics, and observational methods. This may include student feedback, analysis of discussion posts, and instructor observations.

Step 6: Populate the Heatmap

Input the collected data into the heatmap. Each cell should reflect the observed levels of interaction, indicating how well each modality supports meaningful learning.

Step 7: Analyze and Reflect

Once populated, analyze the heatmap to identify trends. For example, face-to-face settings may show high levels of student–teacher interaction but lower student–student interaction, while blended learning may show a more balanced approach. Reflect on these insights to inform future course design and delivery.

Implications for Course Design

By utilizing a heatmap rubric, educators can tailor their courses to enhance meaningful learning. If a particular modality shows low interaction levels, adjustments can be made, such as incorporating more collaborative activities in online settings or increasing feedback opportunities in blended courses.

LITERATURE REVIEW

Based on a meta-analysis of 200 peer-reviewed articles (refined to 187), research studies were classified according to the combination of course modality and interaction type that most effectively promotes meaningful learning, consistent with established interaction frameworks in distance and higher education research (Anderson, 2003; Bernard et al., 2009; Garrison, 2017; Moore, 1989).

In face-to-face learning contexts, student–content interaction is reflected in studies emphasizing active engagement with instructional materials and structured learning tasks that promote understanding and knowledge construction (e.g., Afram et al., 2026; Bailey et al., 2018; Dubinsky et al., 2024; Koernig, 2003; Ramos-Vallecillo et al., 2024; Rossi et al., 2021). Face-to-face student–student interaction is strongly represented in collaborative learning and cooperative learning literature, highlighting peer dialogue, knowledge sharing, and group problem-solving as key mechanisms for learning (e.g., Bruffee, 1999; Johnson & Johnson, 1999; Slavin, 1995; Scager et al., 2016; Topping, 2005; Webb, 1989, 1994; Van Ryzin et al., 2019; Zhang et al., 2022). Face-to-face student–instructor interaction is supported by research on teacher immediacy, classroom relationships, and instructional influence, which consistently demonstrate the importance of instructor presence in shaping engagement and achievement (e.g., Chickering & Gamson, 1987; Cornelius-White, 2007; Hamre et al., 2013; Pennings et al., 2020; Roorda et al., 2011; Ramsden, 2003; Zhang, 2024; Li, 2021).

In blended learning environments, student–content interaction is reflected in studies examining how instructional design, digital resources, and blended pedagogical structures support learning engagement and outcomes (e.g., Akai, 2022; Bennett et al., 2014; Capone, 2022; De Bruijn-Smolders, 2024; Doubet & Carbaugh, 2020; Ipinnaiye et al., 2024; Seaton & Thoms, 2016; Smith, 2022; Ye et al., 2023; Kettlehake, 2025). Blended student–student interaction is evident in research on collaborative learning, peer engagement, and networked interaction patterns in hybrid environments, highlighting the role of peer exchange in improving participation and achievement (e.g., Bekele, 2025; Gitinabard et al., 2017; Han & Bhattacharya, 2021; Johansen et al., 2022; Moodley, 2023; Li, 2025; Tan & Hew, 2016; Tayebinik & Puteh, 2015). Blended student–instructor interaction is emphasized in studies addressing instructional presence, feedback, and teacher facilitation within hybrid environments, where instructor guidance remains central to student success (e.g., Arnett, 2016; Babb, 2013; Chen et al., 2026; Li J-L, 2026; Mizza & Rubio, 2025; Su et al., 2023; Pham, 2025).

In online learning environments, student–content interaction is widely discussed in relation to self-directed learning, instructional design, and engagement with digital materials, which collectively influence satisfaction and achievement (e.g., Al Mamun, 2022; Bond et al., 2020; Joksimović et al., 2019; Kuo et al., 2013; Lee, 2010; Meyer, 2014; Murray, 2013; Su, 2021; Zhao et al., 2023). Online student–student interaction is strongly represented in research on peer communication, social presence, and collaborative discourse in virtual environments, which are critical for learning effectiveness and engagement (e.g., Borup et al., 2020; Gao, 2020; Guiller et al., 2008; Rovai, 2002; Swan & Shih, 2005; Wang & Chen, 2019; Huang et al., 2023; Xiao & Long, 2026). Finally, online student–instructor interaction is addressed in studies emphasizing teaching presence, feedback, and instructor responsiveness as essential factors influencing learner satisfaction and performance (e.g., Arbaugh, 2008; Ascough, 2007; Baber, 2020; Kidder, 2015; Li, 2022; Mullen, 2006; Ong, 2023; Orcutt & Dringus, 2017; Padilla Rodriguez & Armellini, 2014).

Overall, the literature demonstrates that learning outcomes across face-to-face, blended, and online modalities are consistently shaped by the interplay of student–content, student–student, and student–instructor interactions, reinforcing the centrality of interaction as a foundational construct in educational effectiveness research (Moore, 1989; Bernard et al., 2009; Garrison, 2017).

RESEARCH METHOD

Generating Heatmap Rubric

Articles were tallied for each combination, and the results were visualized as a 3 × 3 heatmap, as illustrated in Table 1. Each cell of the grid represents a specific modality–interaction pairing, with the vertical axis denoting instructional modality (face-to-face, blended, and online) and the horizontal axis denoting interaction type (student–content, student–student, and student–instructor). The numerical value in each cell indicates the number of studies supporting meaningful learning within that combination. The color gradient reflects the magnitude of meaningful learning; darker shades correspond to a larger body of studies and, consequently, stronger evidence of meaningful learning within that instructional context.

Table 1

Heatmap Distribution of Empirical Studies Supporting Meaningful Learning (N = 187)

Course Modality	Student–Content	Student–Student	Student–Instructor
Face-to-Face	**12**	**28**	**16**
Blended	**20**	**37**	**27**
Online	**21**	**15**	**7**

Note. Cell shading indicates the concentration of empirical evidence supporting meaningful learning. Darker gray shading corresponds to a higher frequency of studies (e.g., Blended/Student–Student), while lighter shading corresponds to a lower frequency (e.g., Online/Student–Instructor).

RESULTS

The heatmap grid demonstrates that areas of high intensity are concentrated around blended learning modalities, indicating higher levels of meaningful learning across all interaction types. This finding is consistent with the conclusions of several meta-analyses. While face-to-face learning remains the strongest environment for fostering relational and collaborative engagement, it is often less efficient for content interaction alone. Conversely, online learning supports student autonomy and content mastery but frequently yields lower social and instructor presence unless the instructional design is meticulously structured.
Notably, the aforementioned classification echoes a robust body of scholarship and empirical synthesis. This discussion draws on both foundational frameworks and meta-analyses, including Chickering and Gamson (1987), Moore (1989), Garrison et al. (2000), Bernard et al. (2009, 2014), Means et al. (2013), and Borup et al. (2020). Collectively, these works highlight the relative impact of various interaction modalities across in-person, blended, and online learning contexts.

DISCUSSION AND CONCLUSION

A heatmap rubric offers a valuable tool for assessing the interactions that drive meaningful learning, grounded in the Interaction Equivalency Theorem. By examining the combination of course modality and types of student interaction, this meta-analysis identified patterns in which instructional approaches and interaction types most strongly support meaningful learning outcomes. These results provide a framework for understanding how various learning environments and interaction dynamics contribute to student engagement, knowledge construction, and overall satisfaction with the learning experience. By understanding the dynamics between course delivery modalities and interaction types, educators can create more effective learning environments that cater to diverse student needs, ultimately enhancing the educational experience. Embracing this approach will ensure that all learners can thrive, regardless of the modality through which they engage with course content.

Considerations for Future Research

The next phase of this research will proceed in two stages. First, the heatmap analysis will be refined to categorize each mode of student interaction according to the topical concepts proposed by Padilla Rodriguez and Armellini (2014). These concepts include: (a) level of engagement with course activities, (b) depth of reflection on course topics, (c) extent of instructor support in content comprehension, (d) sharing of valuable learning experiences with peers, and (e) overall satisfaction with the learning experience. The heatmap will then be expanded to provide a more detailed and comprehensive depiction of the three-way interactions among these factors.

The second stage will involve follow-up empirical confirmatory research to further examine the heatmap rubric's content, design, and implementation. Data will be collected on the rubric's specific components as it is applied across a variety of classroom settings and teaching modalities, thereby establishing its validity and reliability.

AI Use Disclosure Statement

Artificial intelligence tools were used to assist in the organization and synthesis of literature for this manuscript. Specifically, AI support was used to help sort and classify references into thematic categories related to student–content, student–student, and student–instructor interactions across face-to-face, blended, and online learning contexts. The AI-assisted process included initial screening of references, thematic grouping based on conceptual relevance, and formatting support for narrative presentation. All final decisions regarding the inclusion, categorization, interpretation, and presentation of sources were made by the authors. The authors are fully responsible for the accuracy, originality, ethical integrity, citation correctness, and intellectual content of the manuscript.

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