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GUEST EDITORIAL

Situating multi-modal approaches in engineering education research

1 | BACKGROUND

Traditionally, engineering education researchers rely on quantitative, qualitative, and mixed- or multi-method approaches for their research designs, each with its nuances, set of rules, and worldviews. Here we present a new approach that is yet to be widely accepted in engineering education research (EER): namely the multi-modal approach. This guest editorial is particularly timely because, in 2020, the EER taxonomy underwent a revision (Version 1.2), where the term "multi-modal approaches" was added to Section 12.d.iv (Finelli, 2020). With this addition to the taxonomy, it is important for EER scholars to understand what multi-modal approaches entail and how they are different from other approaches present in mixed-methods or multi-methods. To clarify this new approach further, we give examples of how multi-modal research is used in EER and other related studies.

2 | INTRODUCTION

Rooted in sociolinguistic approaches, multi-modality centers on multiple modes of communication and representation (e.g., reading, writing, and speech) to study meaning-making. In multi-modality, meaning-making includes multiple dynamics or representations of phenomena (or layers) and sensing modes by which an individual recognizes or becomes aware of the complexity of experienced phenomena (e.g., Ledin & Machin, 2017). Multiple sensing modalities are what give an individual "a wealth of information to support interaction with the world and with one another" (Turk, 2014, p. 189), and these can be interpreted through senses such as, but not limited to, hearing, seeing, touching, and feeling (e.g., Ledin & Machin, 2017). Phenomena, in the multi-modal sense, include the "binding of inputs from multiple sensory modalities and the effects of this binding" (Lachs, 2017) on individuals and accounts for the influence that one sensory modality has on another (Spence et al., 2009). Taken together, multi-modal approaches aim to capture the *multi-layered* and *near-real-time* ensemble of the intersections and dynamics of meaning-making (e.g., Archer & Newfield, 2014).

Take, for example, the experience of listening to a song. When a person listens to a song, multiple events happen almost simultaneously: a person hears the song, reads the song lyrics, and thinks about how the song applies to their life. If the song connects with a person on a deeper level, their emotions manifest as excitement or joy, their heart palpitates, their mood changes, and they almost immediately begin to memorize the lyrics and tunes. Analogously, multi-modal approaches try to collect many simultaneous events in order to represent the messiness and immediacy of life.

Multiple layers of the phenomena include both the context and nature of discursive practices while also accounting for the convergence and divergence of its sensing modalities (Archer & Newfield, 2014). Together, the layers and immediacies of multi-modal approaches allow scholars to further nuances in meaning-making as it relates to complex realities such as access, social justice, and equity (Djonov & Zhao, 2013), race (e.g., Mills & Unsworth, 2018), ethnicity (e.g., Lewis Ellison & Esposito, 2021), gender and sexuality (e.g., Leppänen & Tapionkaski, 2021), and intersectionality (e.g., Bagga-Gupta, 2012; Mejia et al., 2018; Villanueva, Di Stefano, et al., 2019).

Furthermore, multi-modal approaches assist scholars in considering multiple means of representation, communication, and contexts by individuals as they study different domains such as literacy education (e.g., Tucker-Raymond et al., 2007), science education (e.g., Tang et al., 2014), design education (e.g., Milovanovic et al., 2021), computing education (e.g., Ciston, 2019; Mangaroska et al., 2020), among others.

3 | DIFFERENCES BETWEEN MIXED-METHODS, MULTI-METHODS, AND MULTI-MODAL APPROACHES

Mixed-methods research (Figure 1a) purposefully integrates both quantitative and qualitative approaches within a single research study (Creswell, 2021). Its premise is that integrating both types of findings throughout or at key points of a research design will allow a phenomenon to be compared, contrasted, and confirmed (Creswell, 2021). The research designs in mixed-methods approaches are generally either convergent (where both qualitative and quantitative data are collected in parallel) or sequential (either the qualitative or the quantitative approach precedes the other). In mixed-methods, conceptual/theoretical frameworks, worldviews, or methods are typically focused on a single phenomenon. Because of its focus, quantitative and qualitative data collection and analysis require triangulation typically from a single disciplinary lens (e.g., social science). This triangulation process draws meta-inferences, usually in tabular form (e.g., joint table), to connect multiple data types and find relationships that can be compared against existing literature, conceptual frameworks, or theoretical frameworks (Creswell, 2021).

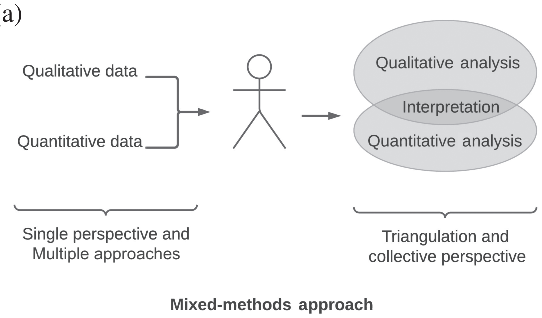
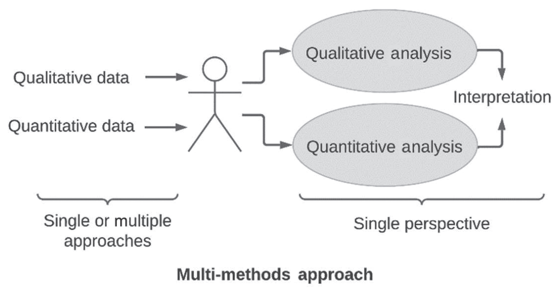
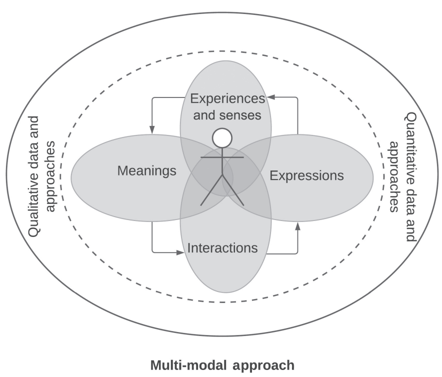
Diagrammatic representation	Approach
(a) 	Mixed-methods approach The focus is on triangulating both quantitative and qualitative data sources to integrate findings and drawing meta-inferences from this integrated analysis
(b) 	Multi-methods approach The focus is on using multiple data sources or approaches to confirm one set of findings with another
(c) 	Multi-modal approach The focus is on a meta-understanding of phenomena by capturing multiple layers of representative data in *near -real-time*

FIGURE 1 A conceptual framework developed by the authors to explain multi-modality. (a) Mixed-methods approach; (b) multi-methods approach; (c) multi-modal approach

In contrast, in multi-methods (or multiple methods; Figure 1b), the qualitative and/or quantitative data are not necessarily integrated in the analyses, but rather the finding from one data source is used to support the other (Anguera et al., 2018). Methodologies (e.g., case studies, phenomenography, narrative inquiry) along with multiple methods (e.g., focus groups, interviews, surveys) can be used to describe a phenomenon. Also, the timing of qualitative or quantitative data collection may vary. For example, an individual may fill out a survey that includes both quantitative and qualitative items and soon after its completion, participate in a focus group. All data collected are analyzed independently to confirm or support a primary data source or focal area in a research study. For both mixed-methods and multi-methods approaches, the collection and use of qualitative and quantitative data can be of equal or unequal weight (e.g., QUAN → qual, where QUAN is the dominant approach).

Multi-modal approaches require capturing multiple phenomena simultaneously and in near-real- time. This means that if a participant completes a survey, other data sources are collected in parallel (e.g., video, facial expressions, sensory data) as they complete the entries to that survey. In this way, data streams are captured simultaneously and in multi-layered forms where each layer represents different dynamics or representations of phenomena. All data streams are collected with the goal of capturing the complexity of participants' experiences. In the same vein, because multiple data layers are captured in near-real-time, analysis and interpretation of the data may require multiple sets of tools and/or expertise (e.g., psychology, physiology, neuroscience), multiple frameworks (e.g., intersectionality, literacy, community cultural wealth), and potentially comprehensive approaches to handle big data (e.g., machine learning, statistics, artificial intelligence). Since multi-modal approaches are not necessarily bounded by disciplinary practices and standards, the researcher(s) may need to develop their own strategies. It also signifies that those processes for comparison, weighing, validation, and triangulation are subject to the research goals, provided that multi-layered and near-real-time meaning-making are captured and interpreted in the process.

In the diagram explaining multi-modal approaches (Figure 1c), an individual can interact with given phenomena by sensing and experiencing their environment, making meanings of interactions of layers within phenomena, and expressing multiple experiences in ways that can be quantitatively measured and qualitatively explored. Both multi-methods and mixed-methods approaches explore a phenomenon or components of a phenomenon but mixed-methods does not necessarily require internalization and/or externalization of simultaneous and multiple layers of phenomena, which is the premise of multi-modal research.

4 | EXAMPLES FROM EER AND OTHER FIELDS

Since the use of multi-modal approaches is still early in EER, we share some examples of how scholars in EER and other fields have used these approaches. To our knowledge, the first evidence of the use of multi-modal research in EER came from Villanueva et al. (2014, 2018); Villanueva, Di Stefano, et al. (2019); Villanueva, Husman, et al. (2019); Villanueva Alarcón et al. (2021), soon followed by Goodridge et al. (2014) and Husman and colleagues (Husman, 2015; Husman et al., 2019). Villanueva et al. (2014) began to use electrodermal sensors, hormonal biomarkers (e.g., testosterone, progesterone, dehydroepiandrosterone-DHEA), and emotion-based surveys to explore how engineering students perform in well-established spatial ability tests. Goodridge et al. (2014) similarly studied students' performance on spatial ability tests using 16-channel electroencephalograms to calculate neural efficiencies of brain activities and their connection to performance. Husman and colleagues explored the roles of emotional regulation, perceptions of instrumentality, and diurnal cortisol when engineering students participated in either exam (Husman et al., 2019) or reflections on an ethics course (Husman, 2015). Subsequently, Villanueva, Husman, et al. (2019); Villanueva Alarcón et al. (2021) collaborated to identify how time-stamped self-efficacy, nervousness, emotions, performance, effort, salivary biomarkers of stress, and electrodermal activity manifested in engineering students taking an authentic statics exam.

Recent work by Atiq (2018) and colleagues (Wert et al., 2021) used multi-modal approaches to study students' emotions during programming tasks. In Atiq's studies, students' synchronized biometric data (i.e., facial expressions, eye gaze tracking, electrodermal activity) were measured using the iMotions platform (iMotions, 2015) along with students' self-report of their emotions via the Achievement Emotions Questionnaire instrument (Pekrun et al., 2011) and a short post-task interview. Furthermore, Villanueva, Di Stefano, et al. (2019) used physiological electrodermal sensors along with interview protocols to conduct intersectionality-informed research to explore the experiences of academic mentoring of graduate students and faculty in science and engineering. Together, these researchers have argued for the need to weave together different data sources and expertise to understand how engineering students experience the context of their learning or research environments.

In addition, some researchers are peripherally using multi-modal approaches in the context of design education and learning sciences, although they may have not identified their studies as including multi-modal approaches. For example, Frick et al. (2021) describe an Analysis of Patterns in Time (APT) approach. The authors argued that traditional quantitative and qualitative approaches are insufficient for complex phenomena such as students' learning journeys and formative evaluation of learning design. They suggest creating temporal maps for real-time tracking of students' interactions and considering other environmental factors to capture the essence of students' experiences. Frick et al. (2021) emphasize the importance of collecting multiple sources and layers of data, which is driven by many contextual factors.

Similarly, Shojaee, Cook-Chennault, et al. (2021) described students' use of, interaction with, and experience of digital games in a learning environment as complex phenomena. These authors assessed students' gaming experiences during game play using simultaneously collected performance and eye gaze data. They quantified the collected data and used them to describe students' attention to a digital engineering game and its game elements. The authors suggested that qualitative or quantitative studies alone are not suitable for exploring the meanings and internalization of such experiences. Similarly, other researchers have used multi-modal approaches to study cortical activation and neuro-cognitive feedback in engineering design (e.g., Shealy et al., 2020) and temporal brain network analysis (e.g., Milovanovic et al., 2021). All these studies employed neuroscience and design education approaches and explored the experiences of students in near-real-time using multi-modal approaches.

Collectively, these examples showcase an evolving desire and interest in the EER and other scholarly communities to use and apply multi-modal approaches in their research designs. We encourage other EER scholars to explore how multi-modal approaches are conceptualized and recommend considering how the dynamics and interactions of meaning-making can be explored in layered, simultaneous ways with this approach.

5 | FINAL THOUGHTS

People interact and sense the world around them in inherently multi-modal ways (Bunt et al., 1998). With the evolving need to capture complex phenomena in near-real-time, multi-modal approaches present opportunities for researchers to study the complexity of the human experience. With an increased call for more critical and intersectional work (e.g., Mejia et al., 2018), multi-modal approaches can be used as either a separate or complementary component of mixed-methods and multi-methods designs in EER scholarship.

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