Sketching Assessment in Engineering Education: A Systematic Literature Review

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***Abstract*—This research Work In Progress systematically reviews the current literature on sketching assessment in engineering education. Sketching is an integral part of the engineering curriculum for conceptual understanding, communication, and design. Sketching enables designers to offload, view, share, and test their ideas. In addition, sketching serves as a tool to increase students' spatial reasoning skills, which is critical to retention and success in engineering. Due to its impact, sketching has been studied in a variety of ways and settings and there are a wide array of methods for assessing sketching. Researchers often assess sketching skill through expert judgment, and when actual sketches are assessed, there are many different metrics that are used. This study is a systematic literature review of sketching assessment exploring applications, cognitive dimensions, and metrics. Databases namely Engineering Village, APA PsycInfo, and Education Source were searched for finding relevant literature related to sketching assessment. Data collection criteria included papers at the high school and college level in engineering, design, architecture, and art. In this paper, our search strings and summary of the final literature sample at the abstract level in terms of publication sources, year, and reviewer decisions are presented. Future directions include continuation of content analysis at the full paper level and assigning quality rankings. The end goal of the project is to provide the design and education communities with a succinct recommendation on sketching assessment to unify efforts in sketching research across the literature.**

***Index Terms*—sketching, assessment, systematic literature review**

I. INTRODUCTION

Sketching is highly beneficial in engineering education and a critical skill for engineers in practice. Freehand sketching is conducive to the early stages of design where ideas are constantly generated and modified as a means of exploring possibilities [1], as well as identifying and refining design concepts later on [2]. Sketching enables communication for thinking in a team, talking about ideas, and storing ideas for future reference [3]. Sketching plays a role in multi-modal communication for engineering design along with gestures, discussion, and idea representation [4]. Sketches are an outward extension of internal thought processes which can be reinterpreted to add new information to existing ideas during the design process [5]. Sketching gives students the tools and symbolic language to strategically represent design ideas and produce new ones from imagination [6]. It also fosters language development through idea generation, creativity, and scientific documentation [7]. More frequent sketching is predictive of a higher quality design outcome among engineers [8] and sketches are an evidence of conceptual knowledge and information [9].

Spatial abilities of 3D perception, visualization, and interactions with representations can also developed in students through sketching. Spatial reasoning involves creating representations of abstract information, such as concepts or schema, and translating them into tangible artefacts. Development of these skills begins in the early years as children explore their surroundings, linked with development of fine motor skills [10]. Spatial skills such as spatial perception, spatial visualization, and mental rotations have been demonstrated to improve after educational interventions in freehand sketching instruction [11], [12], which in turn improves academic performance and retention in engineering programs [10]. Spatial ability is also predictive of success in problem-solving and visualization in engineering. [13].

With artificial intelligence being applied to engineering education contexts for adaptive and personalized learning, digital design tools have the potential to support sketching through more high-quality interactions [14]. Digital sketching materials offer advantages over physical paper-and-pen sketching while still supporting the perceptual and motor aspects of learning to sketch. Tablet sketching enables drawing layers, shading, rendering, and editing compared to pen and paper sketching [15]. Intelligent tutoring with digital sketching is a new technology that offers personalized instruction, feedback, and guided practice for skill development [16]. AI-based sketching instruction makes it more scalable, accessible, and also enables students to master sketching at their own pace [17], which is not practically possible with traditional sketching instruction in large classrooms.

In order to see the effects of sketching skill development in individual students and classrooms, our focus changes from broader long-term outcomes to more specific educational impact. Assessment at the classroom level is necessary to understand the effectiveness of sketching as a learning strategy in engineering education [18]. In sketching education, assessment can focus on the process of sketching [6], [19] or evaluating the sketch itself [20]. In creative product evaluation, such as portfolios, instructors can assign scores to sketches, but the sketch features or students' skills that instructors are grading sketches on can be unique to each case [21] making it a subjective process. Further, the metrics used to analyze sketching can be diverse. For example, Joshi [22] listed 31 overlapping metrics from the mechanical engineering literature including complexity, subject matter, motion indicator, isometric/orthogonal/multiple views, proportion accuracy, and annotation. Yang and Cham [8] found that sketching ability is also highly context-based, influenced by factors such as type of drawing task, amount of instruction, and purpose of sketching. In addition, they argue that sketching fluency depends on a designer's ability to sketch as a way of thinking, while also considering sketching skill and sketch requirements [8].

Because sketching exists in many disciplines, there is variation in how sketching is assessed, making it difficult to consistently define sketching skill and high-quality sketches. The purpose of this study is to examine the state of sketching assessment across disciplines, with the goal of exploring the variety of skills and abilities which instructors and researchers view as central to sketching. This study will investigate how sketching ability is quantified and assessed across the literature, in order to understand its impact on engineering teaching and learning.

Our study is guided by the following research questions: *RQ1: How is sketching ability conceptualized and measured by assessment literature?*, *RQ2: What are the purposes of sketching assessment?*, and *RQ3: What cognitive aspects are used to justify assessment?*

II. Methods

A. Research Questions

This study follows the systematic literature review methodology outlined by Borrego, Foster, & Froyd [23]. Of the purposes and goals for systematic review listed by the authors, ours best aligns with the motivation to describe the state of knowledge or practice on a topic. The scope and research questions were defined by focusing on studies involving freehand sketching in learning contexts. Our aim is to understand what about sketching is being assessed, how and why sketch assessment is used, and whether any connection to underlying learning and cognition theories is being made.

B. Inclusion and Exclusion Criteria

Second, inclusion and exclusion criterias were defined to reflect our research questions while screening papers. Papers from engineering, design, art, and architecture education were included as they consist of the type of freehand idea generating sketches that our study focuses on. Research on computer-aided design (CAD) software were excluded, because it requires technical skills and experience apart from freehand sketching. Studies of students younger than high school were excluded, while studies involving college and/or professional level participants were included. While our search included fields beyond engineering, it did not include other types of technical drawings which are guided by formalized rules and criteria. We targeted peer-reviewed journal and conference papers, but other types could be accepted later depending on relevance.

C. Database Search

Databases that represent the major subject areas of our literature review were selected. Of the available databases three of them that were most specific to our research questions and recommended by the advising librarian for this study was selected. Education Source is the primary database representing the largest collection of education literature in the world, and therefore our main source of literature. Engineering Village, containing the databases such as Compendex and Inspec, is the most comprehensive library of engineering papers in the world; it contains literature outside of education which may include engineering sketching classroom practices or evaluation guidelines. Finally, APA PsycInfo represents literature on formal assessment following psychometric methodology during development and validation, which gives us access to formal assessment literature. While other databases such as Web of Science and Scopus may also contain engineering literature, they are less likely to include studies of engineering education or assessment.

Our search string contains 3–4 components to fully capture our research questions in each database, and is the result of four rounds of iterative testing (see Fig. 1). These search strings were implemented for data collection following Borrego et al.'s [23] framework. The data collection process was divided among three reviewers to search each database. The additional string *(teach OR learn OR instruct*)* was

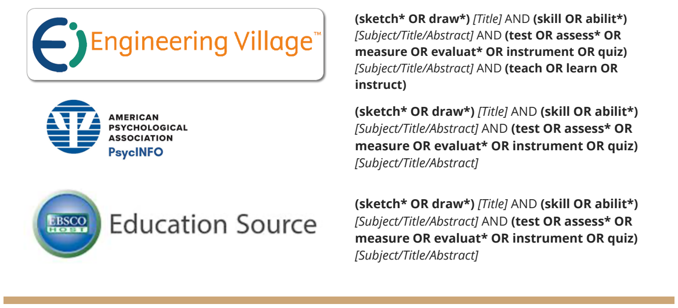

Fig. 1. Search strings by database accessed.

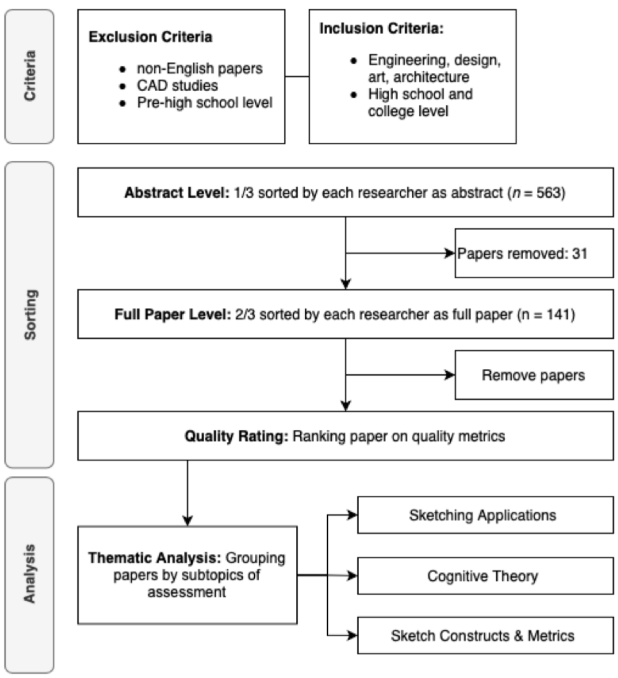

Fig. 2. Systematic review decision process.

used to search Engineering Village for education papers. The downloaded papers were stored in the reference management software Mendeley for shared access.

D. Paper Sorting

Using previously defined inclusion and exclusion criteria, two abstracts were reviewed as a team to ensure consensus on applying the criteria. Each reviewer was then assigned one-third of the abstracts to review independently. We marked abstracts as (a) *Include* for full paper review as clear acceptance in later thematic analysis, (b) *Full Read* for possible acceptance to thematic analysis after full paper review, (c) *Exclude* as not matching our criteria, and (d) *Discuss* the abstract to reach consensus on inclusion or exclusion. This process will be repeated at the full paper stage, and a quality evaluation rubric will be applied to the final dataset to sort papers for thematic and subgroup analyses.

TABLE I
PAPERS COLLECTED BY DATABASE

Database	***n***
Engineering Village	250
Education Source	211
APA PsycInfo	102
Total	**563**

TABLE II
ABSTRACT REVIEW DECISIONS.

Decision	**Count**
Include	38
Full Read	88
Discuss	31
Exclude	305
Duplicate	101
Total	**563**

III. RESULTS

From the previously defined search strings, 250 papers were collected from Engineering Village, 211 papers from Education Source, and 102 papers from APA PsycInfo (see Table 1). Journal papers (n = 410) and conference papers (n = 122) made up the majority of our dataset. From the abstract review stage, 305 papers were excluded (54%), 126 papers were included or advanced to full read (22%), 101 papers were removed as duplicates (18%), and 32 papers required further discussion (6%) (see Table 2). Examples of reasons for reviewer discussion included sketching assessment in children's education, uncertainty about subject or type of drawings being assessed, and uncertainty about what is assessed. Abstracts marked for full read most often included some type of sketching assessment, but did not specify how sketches were assessed or how sketching was defined/measured. Of the 31 papers needing discussion, 1 paper was removed as a duplicate (3%), 15 papers were included or advanced to full read (48%), and 15 papers were excluded (48%).

We found that sketching assessment is a relatively recent topic in the literature, as most of our papers were published within the past 20 years (see Fig. 3). Frequently-used abstract topic words were draw* (n = 1107), students (n = 776), study (n = 482), learning (n = 478), sketch* (n = 433), ability (n = 426), skills (n = 405), and design (n = 250). From the top ten data sources, it was found that the American Society for Engineering Education (ASEE) conference proceedings published the most literature on sketching assessment, followed by humanities and social sciences dissertations (see Table 3). The abstracts were from publication sources such as engineering, clinical psychology, design, art, education, and computer science, indicating that sketching assessment is an interdisciplinary research topic.

IV. DISCUSSION AND LIMITATIONS

Our preliminary results suggest that sketching assessment is a topic of some significance in the engineering education literature, emerging over the past 20 years and extending outside engineering to many fields. Only a small percentage of

TABLE III
TOP PUBLICATION SOURCES.

Data Source	Count
ASEE Annual Conference and Exposition, Conference Proceedings	18
Dissertation Abstracts International Section A: Humanities and Social Sciences	16
Journal of Clinical Psychology	14
Journal of Physics: Conference Series	13
British Journal of Developmental Psychology	10
Studies in Art Education	9
Lecture Notes in Computer Science	8
Computer Applications in Engineering Education	7
Perceptual & Motor Skills	6
International Journal of Engineering Education	6

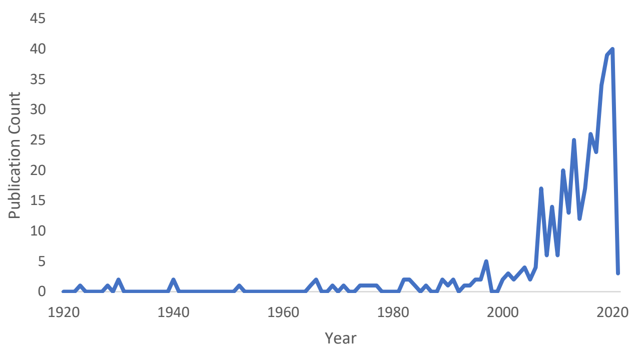

Fig. 3. Publications by year for initial paper dataset (n = 563).

final papers are expected to be relevant for systematic literature review due to the prevalence of sketching in literature which met our exclusion criteria, such as developmental research and younger students. Although conducting a systematic review of interdisciplinary literature while adhering to inclusion and exclusion criteria is challenging, our research aims are supported by these early results that show research in sketching assessment across multiple fields. From an overview of abstract topics, it can also be seen that technology plays a role in sketching learning and assessment, and also classroom-based studies.

V. CONCLUSIONS AND FUTURE WORK

Work in progress shows that there is relatively little research being conducted on sketching assessment in the collected papers, and most of the work is related to factors outside of our inclusion criteria. An increase in sketching assessment literature may be linked to wider use of CAD in engineering education, along with a recognition of sketching as a prerequisite for CAD proficiency. While many papers discussed sketching as a measure of other constructs, few were focused directly on assessing freehand sketching skills. In addition, many papers at this stage are interdisciplinary work, combining domains such as design, art, and engineering. Full paper analysis will investigate the educational contexts of these studies to know the purposes of assessment and the metrics that were used.

Our goal is to understand the diversity of sketching assessment and its purpose in the engineering design and education literature through systematic literature review. To accomplish this, we intend to explore publication sources and identify the fields they originate from, especially emerging and interdisciplinary research. We will also continue to differentiate freehand sketching literature from CAD literature in order to understand how the separate skills are assessed. Future results will inform wider sketching research by comparing and contrasting constructs, metrics, and practices across and within fields.

Full paper review results will also summarize paper content on sketching metrics and constructs across papers using thematic analysis for subtopics. Sketching constructs will be compared to identify the areas of motor, cognitive, and/or design activity the assessment is evaluating students on. The metrics will be identified by investigating how these abilities are observed in sketches or sketching activity. Finally, the applications of sketching in the educational setting, score use, and outcomes of the assessment will be examined. The quality of each study will also be appraised by determining whether the sketching constructs and metrics were clearly defined: if the instrument was aligned with cognitive theory, if assessment results informed student learning, and if evidence of validity and fairness was included. Applying this framework will not remove additional papers from the data set but rather identify subgroups for later synthesis.

Our results will inform future instrument development to asses sketching skill for research and/or classroom use. By systematically identifying existing construct definitions and metrics, our results will contribute to improvements in assessment. In this way, we hope to contribute to sketching assessment research with a better understanding of its foundations and ongoing discussions.

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