An Intelligent Educational Platform for Training Spatial Visualization Skills

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ABSTRACT
Current research has demonstrated the crucial role of spatial visualization skills in the Science, technology, engineering, and mathematics (STEM) related fields. Given the nationwide trend of the increasing population of university engineering students, more and more effort has been invested into how to effectively train students' spatial visualization skills. In this study, we designed and developed a scalable online platform for training spatial visualization skills. Our online platform is capable of intelligent learning features such as individualized learning trajectory and personalized hints. In the current stage of the project, we deployed the online platform with over 600 university students. By analyzing student's data, we identified a key question that has most predictive power on student's spatial visualization skill. The promising result shows a bright future for an intelligent learning platform.

ACM Classification Keywords
H.5.2. Multimedia Information Systems: User Interfaces; K.3.0 Computers and Education: General

Author Keywords
Spatial Visualization Skills; Education; STEM; Personalized Hints; Individualized Learning; Learning Analytics

INTRODUCTION
In the past 20 years, research in engineering education has demonstrated the strong connection between students' spatial visualization skills, which refers to the ability to mentally manipulate 2D and 3D objects, and their learning outcome [?, ?]. Students equipped with sufficient spatial visualization skills are better prepared for learning and solving complex engineering problems [?]. Therefore, researchers and instructors have invested a lot of effort in evaluating and training students' spatial visualization skills.

With the increasing number of incoming engineering students, traditional face-to-face and paper-based workshops are now facing a lot of problems, such as the higher cost for finding enough instructors or teaching assistants and scheduling workshops for larger classes . Moreover, it is very difficult for traditional methods to take advantage of student's learning data and create individualized learning experiences. Therefore, we designed and developed a scalable online platform with intelligent learning features to effectively evaluate and train student's spatial visualization skills in large classes. In the current stage of our work, we deployed our platform to over 600 students in four large entry-level engineering graphics class and analyzed student's error pattern. The result shows a great potential for achieving intelligent features with larger datasets.

IUI'18 Companion March 7–11, 2018, Tokyo, Japan

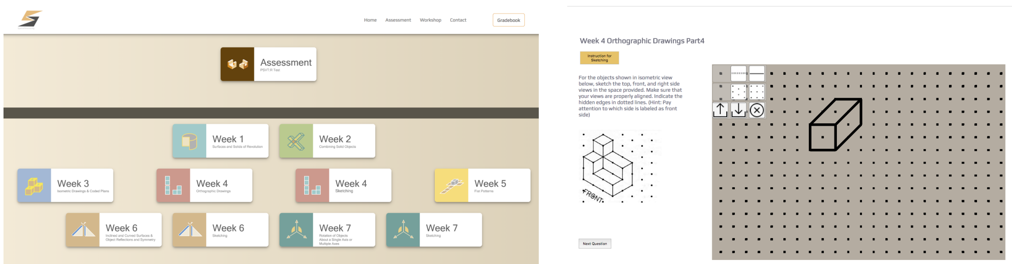
ACM ISBN 978-1-4503-5571-1/18/03.

DOI: https://doi.org/10.1145/3180308.3180370

SYSTEM DESIGN
In the current phase of development, our online platform offers a comprehensive assessment of visualization skills and a set of exercises that were designed to help students to learn effective strategies to solve complex spatial visualization problems (Figure 1). Meanwhile, our scalable online platform allows data-driven learning features such as individualized learning trajectory and personalized hints.

Individualized Learning Trajectory
Our online platform enables the possibility to create a large nationwide database that allows the comparison across classes, departments, and universities. The database also provides the opportunity to apply data analytic techniques to identify various patterns that are difficult to detect by traditional methods such as paper tests. For example, we can identify the key question in the assessment and exercise that has the strongest predictive power on future learning outcome. Moreover, our platform can classify student's problem-solving strategy based on their error pattern. With identified key questions and inferred student's problem-solving strategy, our platform can offer individualized learning trajectory that best suits student's current level of spatial visualization skill.

Personalized Hints
Our online platform collects detailed behavioral data while students are taking the assessment or the test. For example, while students are solving a sketch question, student's progress is recorded stroke-by-stroke. Based on such data, we can reconstruct student's problem-solving progress and infer what kind of strategy he/she used. While students are sketching, our platform can analyze their problem-solving strategy in



(a) Students can take the spatial visualization assessment or training materials through our platform

(b) Students can do free-hand sketching through our online platform

Figure 1: Screenshots from the online platform.

real-time. If the current strategy may lead to an incorrect answer, our platform can provide personalized hints that guide students to the correct problem-solving strategy.

METHOD

We deployed our online platform to four engineering graphic courses in a large university. All courses are designed for freshmen and sophomores with focus on the various aspects of engineering drawings where the spatial visualization skills are strongly emphasized. We chose those courses because instructors from those courses have observed from their previous experiences that student's spatial visualization skill is the key to learning and solving the problems in their classes. All courses have similar goals: (1) to gain familiarity with the standards and conventions of engineering design graphics, (2) to gain exposure to computer-aided design techniques, and (3) to develop sketching skills using different tools. By far, a total of 624 students from these four courses have used our online platform to take the test to evaluate their spatial visualization skills.

Spatial Visualization Assessment

The spatial visualization assessment test is a standard version of Purdue Spatial Visualization Test-Visualization of Rotations (PSVT: R). It is a widely used assessment in evaluating the spatial visualization skills. A total of 624 students from two Theoretical and Applied Mechanics courses (N = 345), one Aerospace Engineering (N = 78) course, and one General Engineering (N = 201) course took the PSVT: R test through the online platform at the beginning of the semester. The average of the PSVT:R test is 22.6 (SD=5.18) out of 30 with similar distribution (M= 22.92, SD= 5.11) Maeda and Yoon [?] found in a large-scale assessment.

PRELIMINARY RESULT

In the current stage of our work, we identified a key question (Q19) in the PSVT:R test that has the most predictive power on the post-course PSVT:R test students got after the class. Although a total of 437 students answered this question correct with the answer "B", we found students who answered "A" for this question (N = 31, M = 13.42, SD = 4.61) got significantly lower total score than students who scored this question (M = 23.48, SD = 4.26), t = -11.78, $p < 0.01$. And students who answered "A" for this question mostly fell into the first quantile of the total score (87 %) (Figure 2).

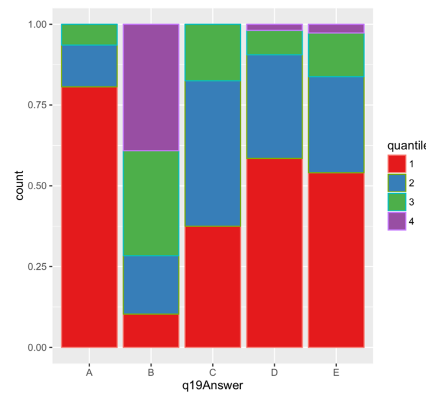


Figure 2: The distribution of students' choice on Question 19 group by their final PSVT:R score quantile

CONCLUSION AND FUTURE WORK

The result we got at this stage shows the potential of our online platform in deploying data-driven intelligent learning features. With only 600 students' data, we have already identified a predictive question. Our next step is to deploy our platform to a larger group of students and implement intelligent features including individualized learning trajectory and personalized hints. We believe with those data-driven intelligent learning features, our scalable platform is able to effectively assess and train student's spatial visualization skill in large scale and prepare students for their future learning in the STEM field.

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