Convergent Classroom: From Nature to Digital to Cognition in Geometry Acquisition

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Abstract. Artificial Intelligence can provide intelligent solutions for the educational system. This article uses an object detection algorithm to explore physical surroundings and extract geometric shapes from two- and three-dimensional objects in real time within or outside a classroom. Having the shapes, the geometry lesson begins. We named it “Convergent Classroom”. We have conducted a post-test only group design in which first-year pupils from secondary school participated in the sessions. Our main results show substantial statistical evidence to support pupils’ higher geometry acquisition engagement using computer vision algorithm, compared to those who did not use it. This nature-to-digital-to-cognition engagement can be further explored by neuroscience measurement to understand what happens in pupils’ brain when they connect geometrical shapes from their surroundings to geometric cognition. Furthermore, these observed significant differences call for teachers to implement the already known algorithms in future classrooms.

1. Introduction
Numerous real-time computer vision applications exist in the industry and markets for the recognition, detection and localisation of real-world objects such as faces, cars and buildings, serving various purposes such as security, surveillance, people counting, packaging, self-driving mechanism of cars, fraud prevention, face recognition in phones and image extraction [1]. Further, the performance of recently developed algorithms, such as the ones that can recognise object categories and extract their features, has improved. These semantic objects are rich in geometric shapes in both two and three dimensions. However, limited evidence exists pertaining to ways of implementing computer vision as an interplay between nature, digital objects and cognition inside the classroom and how these affect students’ performance, particularly in developing countries. In developed countries, education with learning technology has already been introduced and seems to be empowering the education system in theory and practice [2]. Since the arrival of deep learning, there has been a significant improvement in recent object-detection performance and tracking algorithms [3]. They allow computational models to learn abstract, complex and even subtle representations, surpassing professional human activities, including games [3].
On the other hand, there is a strong interest in understanding the nature of human intuition pertaining to the properties of points, lines and other shapes and whether these concepts are innate or learned [4]. Even philosophers including Plato, Descartes and Kant have claimed that geometry comes naturally to the human mind, even to those who lack mathematical knowledge [4]. Further, there are experiments that illustrate how animals orient themselves in space and how their spatial memory encodes geometry, such as birds migrating from one distant habitat to another [3,4]. They possess a natural tendency to recognise complete spatial patterns, even in partial visibility. Therefore, it might be fair to say that everyone is a geometer, even animals; thus, geometry seems to be everywhere.

Consequently, given the progress in technology, cognitive neuroscience and pedagogy, the present paper introduces the novel Convergent Classroom approach, which simultaneously assesses the physical world and uses digital technology to enhance knowledge acquisition, both inside and outside the classroom. We tested this using a geometry lesson to shape the process and ideas around Convergent Classroom, as geometry is everywhere. We modified an algorithm to extract two- and three-dimensional geometric shapes in real time from both inside and outside the classroom such as extracting cylinder from the trunk of a real tree into the computer. Afterwards, all the abstract properties of the geometric shapes were acquired such as dimensions, diameter, surface area, volume and rotation.

In the following section, we present our seminal idea of Convergent Classroom. Section Three describes the research approach and procedure, followed by a discussion, conclusion and future work.

2. **Convergent Classroom**

At any given moment, the environment can explosively unroll, providing us with unlimited sensory stimulation to guide our perceptions and actions [5]. Moreover, people also have selective attention, which is the ability to ignore or inhibit certain information in the environment [6]. Therefore, it seems fair to assert that at a given point in time, different students focus on different aspects of the environment. Considering this, using technology such as computer vision can help pupils to focus and learn.

Convergent Classroom is an attempt to find the single best learning environment to combine students’ cognition with the physical and digital worlds, enabling them to work in harmony (Figure 1). We thus offer a new approach to help teachers and students develop integrated and diverse learning content, tools, disciplines and technology from their environment, complementing each other to enhance and optimise learning. Such an approach can help students better understand their own focus and creativity levels. In this study, we used vivid examples to enact our approach for the object-detection algorithm in geometric cognition.

![Figure 1. Convergent classroom.](image-url)
3. Research Approach and Procedure

Assessing the presence of objects and extracting geometric shapes from student-focused objects of interest inside or outside the classroom is key in implementing our idea of convergent classroom, followed by geometry lessons based on the shapes of those objects. It is not about rote computation but, rather, exploration. Then, questions and answers on abstract concepts of geometry were included in these lessons; however, abstract it can be, but our approach ties geometry to everyday life to digital to cognition.

In this study, the participants consisted of 20 Peruvian secondary school students. 10 of them were in a control group, named Group ‘P’, taught using a whiteboard and power point slides, as usual, while the other 10 were in the experimental group ‘S’, which attended the same geometry lesson as the control group but with the object detection algorithm, which collects and describes geometric shapes. They were identical in every other factor, such as the lesson content and assessments, and the pupils were randomly assigned to one of these groups. Each participant in the experimental group was seated in front of a laptop with the video camera activated. Some were positioned such that video camera could capture objects placed on the table, such as cups, bottles, boxes, etc. only in cases where the camera was not capturing any object or there was only an empty wall on focus.

The control group students were taught the same lesson using the standard first-year lesson plan, which includes PowerPoint slides. The topics covered were volume and surface area.

As depicted in Figure 2, the surrounding physical space was the input for the edge detection algorithm. The geometric shapes constituted the output. The biggest step was to implement this real-time shape detection from three dimensional objects to real objects.

Figure 3 shows the extraction process of a dimension or shape, following which students were asked to describe the three-dimensional objects and the corresponding geometric shape captured by the algorithm. The description included determining the measurement and properties. With such measurements, they could estimate the surface area, symmetry, volume, diagonals, etc. of circles, cylinders, pyramids and cones, where applicable. Students were also able to explore the rotation and translations of the shapes.

\[
L_{\text{equ}}(\theta; \mathcal{V}) = \frac{1}{Q-1} \sum_{t=1}^{Q-1} L \left( D_{\theta}(F_{\theta}(I_t), T_{\tau_{t-1}}(F_{\theta}(I_t))), y_t \right)
\]

Figure 2. The input and output to begin a lesson.
There are many methods for shape-extraction implementation by detecting edges in image processing. In this study, the Sobel Edge Detection Algorithm [7] was adapted which determines the gradient of image intensity at each pixel, equivalent to finding signal discontinuities over time. Once this algorithm processes images, it manipulates mask and finds the absolute magnitude of the gradient to obtain the contour from the mask [7]; the shape is then detected from the contours.

We interviewed the participants; questions were asked in terms of enjoyment and interactivity. Some of the answer statements were as follows:

P1 – I enjoyed visualising the three dimensional shapes.
P2 – I believe this type of lesson can be fun.

We also observed that students who are easily distracted or constantly fidgeting, squirming or restless can concentrate better with this approach.

We collected data through a questionnaire, which was handed out the next day without prior notice. The number of correct answers and solutions were recorded for data processing and the dataset was processed and is explained in the next section.

4. Analysis and Discussion

We first assumed that there is no significant difference between the observed sample means for the experimental and control groups. An experiment was performed to test whether the Convergent Classroom approach improved the pupils’ understanding of the above-mentioned lesson. Since each group was independent of the other, an independent sample t-test was used.
Figure 4 shows that Group ‘S’, the experimental group, presented higher outcomes, congruent with the statistics in Table 1. Each figure was converted into a percentage for plotting the graph. However, the grading system used by the school was from 0-20 scale where the passing grade is 10.5 out of 20.

| Group | N  | Mean | Std. Deviation | Std. Error Mean |
|-------|----|------|----------------|-----------------|
| ‘P’   | 10 | 10.50| 3.440          | 1.088           |
| ‘S’   | 10 | 15.60| 1.955          | 0.618           |

Running the independent sample t-test, we found $p = 0.009$, which is less than the chosen significance level, i.e., $a = 0.05$. Therefore, we rejected the initial hypothesis and concluded that the mean for our nature-to-digital geometry group was statistically significant and different from the mean for the non-nature-to-digital group.

5. Conclusion
The results of the present study provide statistical evidence in favour of the proposed Convergent Classroom (nature-to-digital-to-cognition) approach. The mean of our experimental group was significantly different than that of the control group. Therefore, an improvement in geometry learning was noted when the shapes were extracted from their environment and used to develop students’ understanding. This engagement can be further explored using neuroscience measurements to understand what happens in the brain when pupils apply geometrical shapes from their surroundings to geometric cognition. Convergent classroom can be further improved and used in core math curriculum, and even extend to other subjects.

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