LEGO2NANO: Designing interactive science for children in China

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ABSTRACT
We envisage a future in which Chinese children can participate actively in scientific research by building low-cost scientific instruments, using them to study their environment and sharing the resulting data online for collaborative analysis with crowdsourcing technologies. We have made a first step towards this ambitious goal by launching an international challenge called LEGO2NANO involving collaborations between post-graduate, undergraduate, high school and middle school students. We describe how students involved in the challenge have designed, built and operated a low-cost atomic force microscope to explore their environment. We outline next steps, which involve establishing a facility for collaborative design and prototyping of new low-cost scientific instruments suitable for use in Chinese schools, and a virtual lab on the Web where children can share and analyze their results interactively.

Categories and Subject Descriptors
D.3.3 [**Computers and Education**]: Computer Uses in Education – *collaborative learning.*

General Terms
Measurement, Documentation, Design, Economics, Reliability, Experimentation, Human Factors, Standardization.

Keywords
China, Science, School, Learning

1. INTRODUCTION
China is in the midst of a widespread re-evaluation of its education system. Rote-learning for exams is out of favour, and even the role of the famous Gaokao college entrance exam is being reconsidered, as top leaders search for ways to nurture the sort of innovative talent that can match China's future economic needs.

Chinese children primarily learn science from textbooks, as do their teachers. Even for undergraduate science students, the majority of hands-on experience comes from lab exercises that are highly constrained in order to support textbook learning, and do not reflect the open-ended nature of real scientific enquiry.

What we propose in this article is the pursuit of an emerging technological opportunity that can enable Chinese schoolchildren to gather, share and analyze real scientific data, even for schools on a very limited budget. This technological opportunity builds on the methods of crowdsourcing [1] and citizen cyberscience [2] to gather and share data online, and a trend called frugal science [3], which focuses on lowering the cost of scientific equipment to make it more accessible to people in developing regions.

To explore this opportunity, we organized an international summer school at Tsinghua University in September 2013, where students from a range of disciplines (design, science, engineering…) ages (high school, undergraduate, postgraduate…) and nationalities (China, UK, Singapore…) collaborated on a challenge called LEGO2NANO, which involved designing and building a low-cost atomic force microscope and associated online tools for sharing and analyzing data.

An important feature of this summer school is its focus on collaborative learning between schoolchildren and university students. The rationale for this approach is that when designing interactive science for children, we should involve those children actively in the process, and be inspired by their vision for what they could learn this way.

In future, we plan to extend this "learning cascade", which starts with the students of Tsinghua University - an icon of the Chinese education system - so that it emanates through local high schools and regional middle schools to primary schools across the country. We also want to amplify this process by creating a virtual laboratory where tools, methods and data are shared online.

In the next section we describe the design and implementation of the LEGO2NANO challenge.

2. METHOD AND RESULTS

The LEGO2NANO challenge aims to develop, build and exploit an atomic force microscope (AFM) at a price below 1000RMB (about $160), affordable for a Chinese middle school. To put this challenge in perspective, a laboratory-grade AFM costs around $100,000, and even so-called educational models are typically priced at $20,000.

The LEGO2NANO challenge was launched [4] at Tsinghua University in Beijing as part of a five-day international summer school in September 2013. In a subsequent four-day undergraduate training event at Tsinghua in January 2014, further progress was made towards meeting the LEGO2NANO challenge.

2.1 Teams and clients

In the summer school, AFM prototypes were developed by four teams, each consisting of eight students. These teams were deliberately selected to represent a mixture of undergraduate, masters and Ph.D. students from China (Tsinghua and Peking Universities) and the UK (UCL and Oxford Universities). This was achieved using a team formation algorithm that leverages skill set and personality type indicators [6]. The students came from diverse backgrounds, ranging from physics and computer science to design and psychology. Only a few had used an AFM or knew how the device worked prior to the event.

At the outset of the event, the teams consulted with a group of local middle-school students, the project “clients”, in order to establish what sort of experiments the students could envisage doing with an AFM in their schools.

Though the students knew little about nanotechnology, this did not prevent them from imagining microcosms. When asked, “What do you want to see if you could use AFM to see the nanoscale world?” the students gave many original answers. Some were objects such as a compound eye, dust, an iris. Some were more fanciful, such as the movement of electron, or even light itself.

Some students had only vague concepts of the micro world. One supposed that on the nanoscale, the world is like a universe, and wondered whether there were objects like planets and black holes on that scale. They all showed strong interest in observing the micro world and were particularly keen to see the world on their own, rather than looking at photos in a textbook.

2.2 Hardware Build

AFMs, in contrast to optical and electron microscopes, do not require expensive focusing lens components. Rather, they rely on sensing the direct action between a probe and a sample surface. The principle of the AFM is closely analogous to that of a vinyl record player. Nevertheless, AFMs have costly components, for example, the piezoelectric motors that move the sample relative to the probe with nanometric precision, and the readout system used to detect the motion of the probe. The teams were encouraged to find low-cost alternatives to these and other AFM components.

The structure of the five-day challenge was modeled on the eXtreme Learning Process [5], while setting a deliberately open-ended goal, and encouraging students to cross-fertilize between teams. The emphasis was on creativity rather than competition. As part of the challenge, we introduced the students to methods such as ideation and rapid prototyping [6]. The teams produced 1096 possible solutions for the design with associated sub-problems, and 48 visual mockup prototypes in about 5 hours of ideation.

Kits containing useful materials and components were prepared in advance of the event, including stocks of LEGO, Makeblock, an Arduino and a PCDuino. But the teams were also encouraged to use available tools such as 3D printers, as well as components from local consumer electronics markets in Beijing, to supplement their toolkit. It is worth noting that the students were under no compunction to use LEGO or any other specific component.

The following figures illustrate key steps in the build process.

Figure 1. Student team brainstorming after reviewing the materials available to them at the outset of the challenge.

Figure 2. Rapid prototyping session using paper models, to emphasize the importance of prototyping multiple solutions.

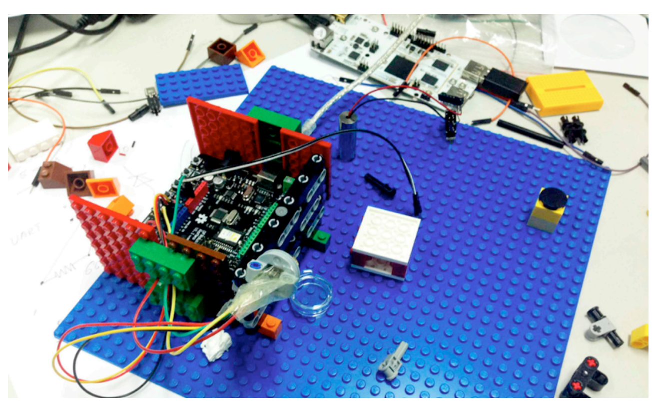

Figure 3. Early-stage prototype of an optical system for detecting the motion of the AFM probe.

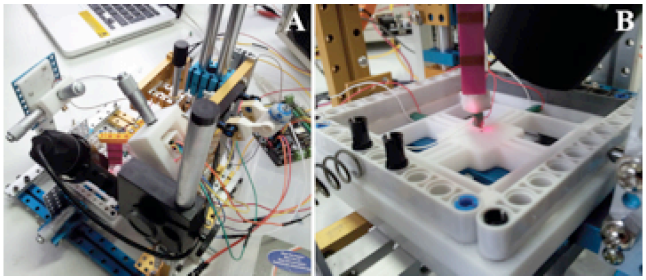

Figure 4: The most successful prototype. Note the mix of materials which include machined metal and 3D-fabricated components, LEGO and consumer electronics.

Although the teams evinced great creativity and enthusiasm, with some students working round the clock to prepare their final demos, the LEGO2NANO challenge did not result in an AFM able to image nanoscale objects.

However, given the limited time available, the teams made impressive progress. The most successful prototype, shown in Fig. 4, could even perform single line scans – an important step towards full raster-scan imaging.

2.3 Software and Applications

Integral to the challenge was the notion of developing an online component of the project where results obtained with a low-cost AFM could be shared and analyzed by schoolchildren, and coming up with a realistic and relevant scientific applications that would inspire such schoolchildren, and could lead to crowdsourcing activities across the country.

Although the majority of the team effort went into the hardware build, they were able to mock up practical software solutions, as illustrated by the website below (English version), which incorporates the sort of functionality that would allow students to share and discuss data they had uploaded from their microscopes.

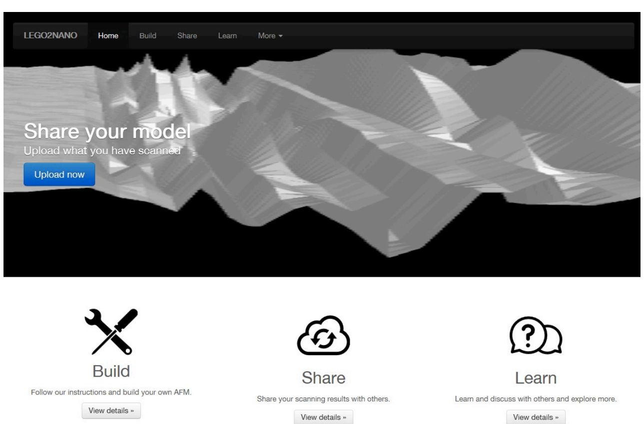

Figure 5. The virtual lab on the Web where children can share and analyze their results interactively.

In terms of practical applications suitable for school-based crowdsourcing, topics proposed by the teams included imaging leaves from trees known to be sensitive to pollution, to observe possible correlations between the nanostructure of the leaves and the degree of pollution they were exposed to in different regions of China.

2.4 Children Interacting with an AFM

The unusual nature of the LEGO2NANO event resulted in considerable press attention in China and subsequently worldwide. As a result, other research groups working on similar low-cost DIY efforts contacted us to share their experiences and learn more about ours.

One of these groups had developed a fully functional AFM that ingeniously uses the cheap piezoelectric buzzers from electronic watches and the readout head from a standard DVD player to replace two of the expensive components of an AFM [7]. While the associated control electronics is still too expensive for schools, this model allowed us to explore what happens when middle schools students build and operate a DIY AFM by themselves.

In the second event in January, a team of middle school students assembled a DIY AFM and used it to scan objects successfully with nanometer-scale precision in less than a day.

Figure 6: Middle school students assembling a DIY AFM.

Figure 7. 13-year old middle school student operating an AFM that he and his classmates have built in a day.

The first research topic chosen by the students was to image an eraser, which under an optical microscope shows no features. In the AFM, the eraser reveals a nanoscale composite structure indicative of how the abrasive material works.

After this, the students imaged microscopic dust particles on a DVD grating, typical of pollution in Beijing. This experiment made visible the sort of particles that PM2.5 pollution detectors are sensitive to, while revealing a much broader spectrum of particle sizes. This led to a discussion amongst the students of air pollution's causes and preventions.

One student was particularly perspicacious. Although he liked science, he had selected art options at school, because they allowed him to be more creative. His first reaction when he heard about the AFM was to wonder what the world would look like if he was an electron. When it came to build and test the AFM, he was able to do so on his own in just an afternoon. The next day, he was able to successfully instruct a group of undergraduate students on how to build the same AFM.

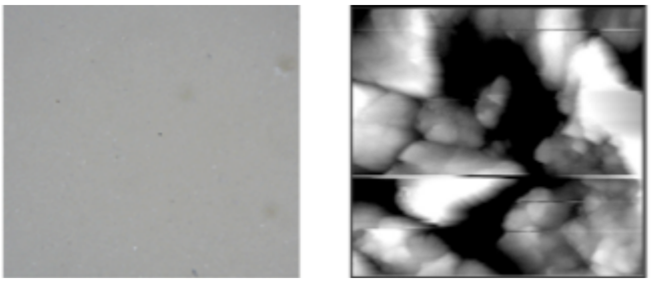

Figure 8: comparison of an eraser as viewed under an optical microscope (left) and with an AFM (right). The AFM image is approximately 5x5 μm^2.

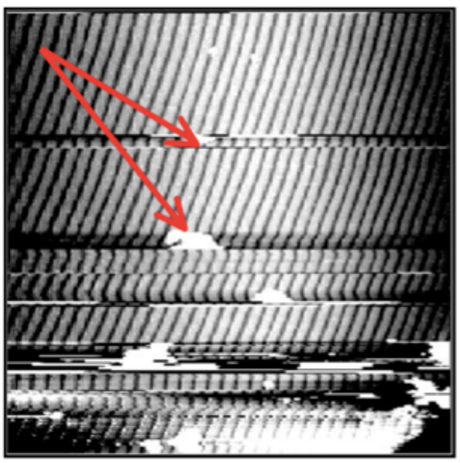

Figure 9: Dust particles approximately 2 microns across detected by the DIY AFM on the groove structure of a DVD.

3. DISCUSSION AND CONCLUSION

The teams have documented their results on the LEGO2NANO website [4]. Some lessons learned worth retaining for future development include:

- Using more robust components to ensure more stable scanning, and in particular replacing LEGO and other plastic components with machined metal components, wherever stability is of vital importance
- Finding a low-cost replacement for the bulky and expensive signal generator used to drive the AFM scans. For instance, commercially available waveform generator chips and power amplifier chips can make up a simple driving system for the piezoelectric actuators with the necessary function of tuning the scanning frequency and output voltage.
- Using a modular design that would be more suitable to illustrate the principle of AFM to middle school students, where the detachable parts have relatively independent functions, and enable students to select optimal settings for a specific type of sample.
- Finding an alternative to conventional AFM probes which are manufactured with MEMS techniques, involving a series of complex and expensive fabrication processes. Commercial probes are about $10 each, and since they wear out quickly, can become a significant component of the overall operation budget for an AFM in a school. Injection molding of plastic probes is an interesting potential alternative.
- As a control platform, PcDuino has useful interfaces to display devices and internet, which can be further exploited. For example, the AFM can be made remotely controllable through the Internet, or the AFM image could be displayed to the audience in real time by a connected projector.

In conclusion, we have established that it is possible for students in just a matter of days to find innovative solutions for drastically lowering the cost of an atomic force microscope, through a directed collaborative learning process. We have also shown that middle school children are able to assemble and operate such low-cost instrumentation, and pursue practical research goals inspired by their own questions about the nanoworld.

The underlying motivation of LEGO2NANO was not just to make a low-cost AFM. Rather, we envisage a low-cost toolkit that makes active participation in a wide spectrum of scientific research more accessible to children in China.

And although the focus of LEGO2NANO was on Chinese schoolchildren, the results are relevant to learning science in classrooms around the globe. It is therefore particularly encouraging to note that we have received requests from researchers as far afield as India, France and Ecuador, keen to collaborate on further developments of this initiative.

We anticipate that combining instruments like the low-cost AFM with digital technologies for sharing data and crowdsourcing its analysis will enable children to collaborate in new ways with their peers on the Internet, and ultimately result in genuinely new scientific discoveries made by the world's most enquiring minds.

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