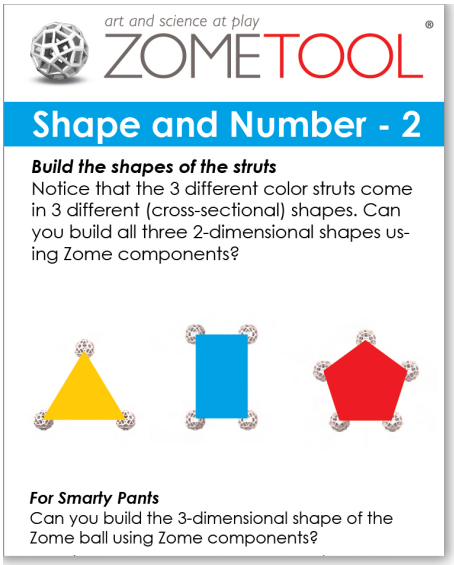

Figure 1: *a Challenge Card*

Zometool Workshop

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Abstract

How to conduct a Zometool workshop for students, teachers or parents using the Zometool, and Challenge Cards (included with the Workshop kit; example, left). Covers the discovery learning philosophy, preparing for the workshop, conducting the workshop, follow-up activities and available resources for educators ("Teaching Resources," on the last page).

1. Introduction

If you want to get kids excited about mathematics, but don't know where to start, try a Zometool workshop. Zometool is a powerful manipulative that applies to many of the (U.S.) national standards (1) and integrates with other core subjects such as STEAM (2) and language arts. And it's fun! This content was developed with K-8 gifted students in the summer of 2006. Based on the "discovery learning" model, it can break the ice in the classroom, facilitate lots of learning, and leave students begging for more!

2. Discovery Learning

Discovery learning "is based on discovery guided by mentoring rather than on the transmission of information," (3) i.e., the discovery process is as important as the learning that results. In a nutshell, you pose challenges and students try to solve them. With lots of ways to solve a challenge, an unusual approach may lead to unexpected discoveries. Some teachers dread the moment they can't answer a student's question. Fortunately, this happens fairly frequently with Zometool. It's liberating to say, "I don't know. But that's a great question. Any ideas on how we could find out?" That's when learning quickens!

3. Preparing for a Zometool Workshop

3.1 Familiarize yourself with Zometool -- work with Zometool before conducting a workshop. This is *not* so you can know all the answers, but rather so you are better able to guide the discovery process. See through your students' eyes. Unstructured play is a good way to start; then work through some of the challenges or lesson plans listed in **Teaching Resources**.

3.2 Organize the learning space -- organize the workshop space into 3 areas: 1) tables, where students can work in teams, 2) a discussion area for the whole group, and 3) plenty of floor space to accommodate larger projects as the workshop progresses. Allow at least 20 m^2 (215 sq. ft.) per team (4-8 students.)

Tables -- use round tables if possible, with enough chairs for teams of 4-8 students, and include 100 (+) Zometool parts per paricipant. Place the tables in a U-shape along 3 walls of the room, with plenty of space between them for bridges, towers, Metazome structures, etc.

Discussion area -- separate the discussion from the tables and arrange seating so that students are encouraged to focus on you and and other participants during discussions. The temptation to continue "playing" with Zometool is too great (even for adults) when it is close at hand! Best if they can't even see their own models during discussions (unless sharing with the group.)

Space for larger projects -- the advanced challenges are an exciting part of the workshop, in which teams build large and complex models. Structures like the "Tallest Tower," "Longest Bridge" or "MetaZome" can have dimensions of several meters. Adequate space helps you control the chaos.

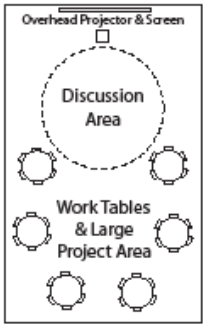


Figure 2: *set up*

3.3 Rhythm and attention span -- Find a natural rhythm for the activities: alternate between challenge sessions, in which the students are engaged in hands-on activities, and group discussions, in which all attention must be focused on one speaker at a time. Don't let basic challenge sessions exceed 15-20 minutes without a discussion break. Initial discussions should be limited to 5-10 minutes. A number of studies (Johnstone & Percival, 1976, and Burns, 1985) suggest that even adults' attention begins to flag after 15-20 minutes in any one activity. In a lecture or discussion, the first 5 minute period has the greatest impact. Attention will increase with student's interest, so advanced challenge sessions may tend to be longer.

3.3.1 Two-Hour Workshop Schedule

Time*	Section	Attention to:	Comments
00:00-00:10	Intro free play	Zometool parts	initial assessments of participants
00:10-00:15	Workshop rules	Facilitator	see section 4.2.1
00:15-00:25	Free play disc. & challenges	Participants & Facilitator	assign basic challenges based on disc.
00:25-00:45	Challenges I	Zometool & team	teams work on basic challenges
00:45-01:00	Challenge I discussion	Participants & Facilitator	assign advanced challenges
01:00-01:30	Challenges II	Zometool & team	teams work on advanced challenges
01:30-01:40	Challenge II discussion	Participants & Facilitator	teams present their final projects
(01:40-01:50)	(Photos)	(Parents)	assumes parents are invited last 20 min.
01:50-02:00	Clean-up	Work area	

*times are flexible, but in general, no session should exceed 20 minutes in length

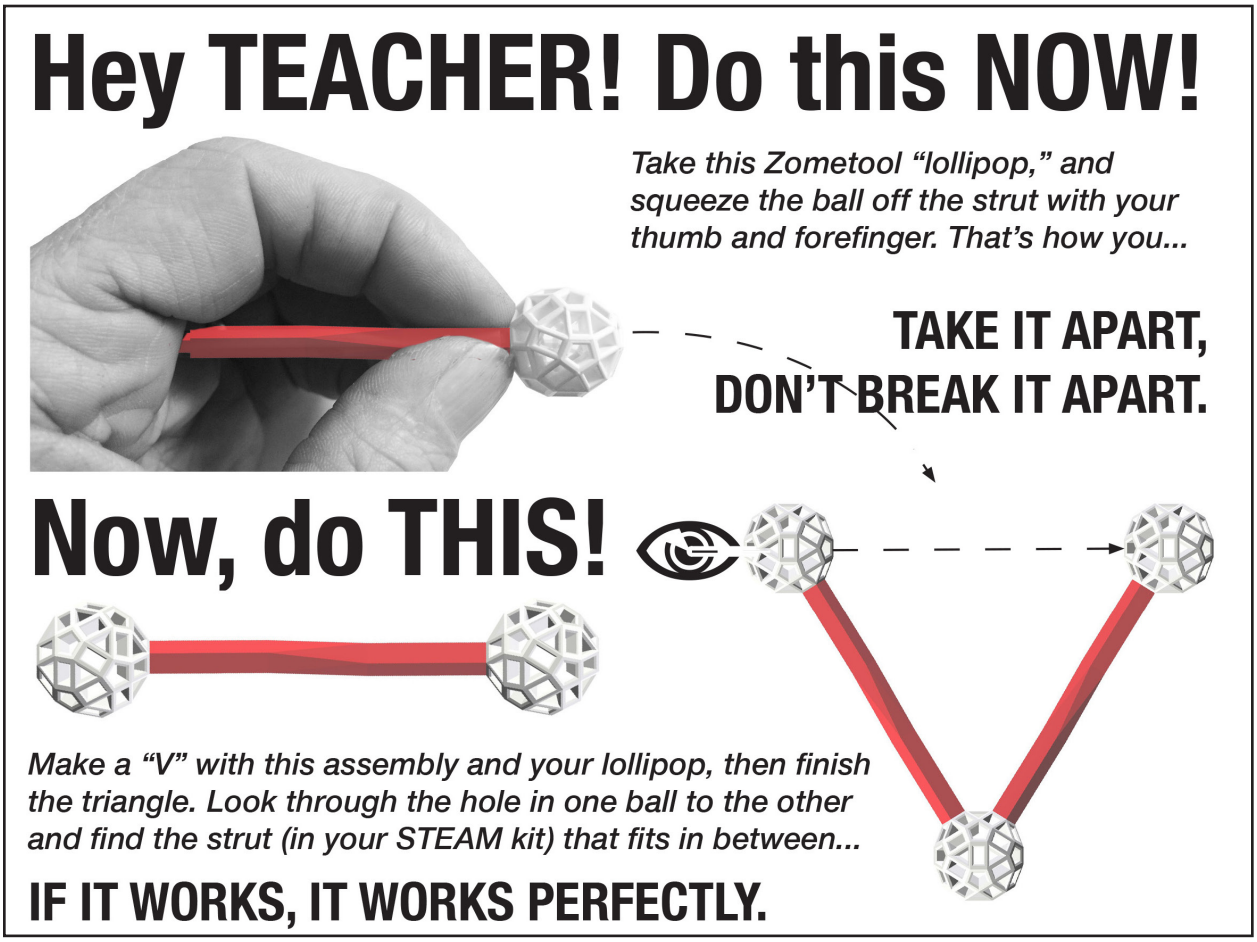
4. Conducting a Zometool Workshop

4.1 Initial assessment -- on arrival, encourage participants to try out Zometool for a few minutes. (If parents bring kids to the workshop, advise them to arrive 15 minutes before the end of the workshop to see their kids' creations, take photos, etc.) Use this time to assess each participant: some will dive in and and start building structures, some may sit back with their arms crossed, some may walk around the room looking at others' work. Your assessments are important to building a successful workshop for all the participants. Use the information to assign challenges, change the composition of groups, avoid conflicts, etc.

4.2 Initial discussion -- After the initial assessment, move to the discussion area to talk about 1) the structure of the workshops, 2) the rules, and 3) what the students learned about Zometool during the "hands-on" session. During this third part, assign challenges and finalize the composition of the teams.

4.2.1 Workshop structure -- briefly explain the structure of the workshop to the group. During hands-on activities, it's o.k. to experiment, create and build, to talk in a classroom voice with team members, and even walk around the room and see what other teams are doing. During group discussions, one person speaks at a time and all attention is focused on the speaker. Keep the discussion area completely separate from the work area. Seeing models is a distraction; being within arm's reach is too great a temptation.

4.2.2 Workshop rules -- frame the workshop as an educational event and not a free-for-all, by demonstrating two rules: "Take it apart, don't break it apart" by squeezing a ball off a strut, and "If it works, it works perfectly" by showing students how to "sight" one ball through the hole of another to find the strut that fits. This can lead into the initial discussion, in which students share their first impressions of the tool.



4.2.3 Discussion -- "So what can you tell me about Zometool?" "The balls have different shaped holes... Some struts are twisted; some are straight... Only certain struts fit in certain holes... There are different colors and different lengths of struts... Blue struts are 'squares'... Yellow struts are triangles... Red struts are 'hexagons'... The struts come in short, medium and long lengths... if you put a short and medium together, it makes a long... Reds and blues are the 'same' length, but yellows are shorter..." [Some of these statements are false.] Let them struggle with ideas. Use questions like "what do you think?" or ask the group, "do you agree? who has a different idea?" to keep ideas flowing. This also saves you from having to know it all. (4)

4.2.4 Assign challenges based on your assessments, and the initial discussion. For example, kids like to build "pincushions" (see Figure 3, overleaf). Challenge them to put balls on the end of the struts and "connect the dots." Then extend the edges until they cross. Then connect the dots again...

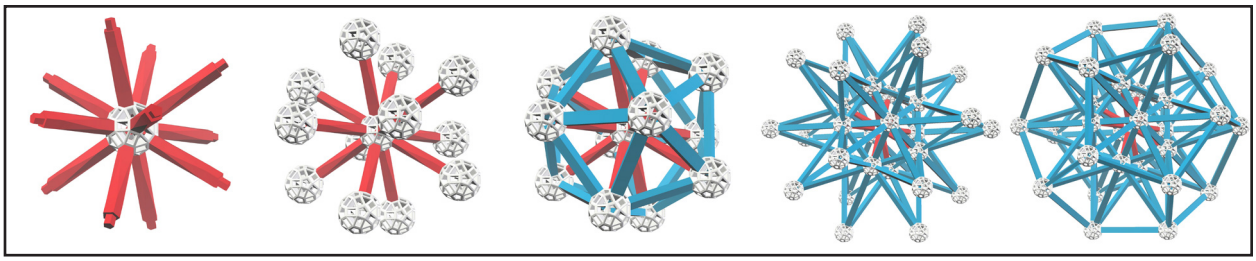


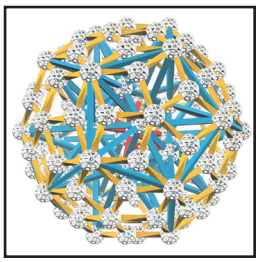
Figure 3: *"What happens if I put a red stut in every hole?" becomes a 2-hour activity: the "pincushion" gets "dots," that connect to form a virus, whose edges extend into 3D star, and beyond...*

Or, a table may have several students who only seem interested in building cubes with the long blue struts.. The "Lego heads" are good candidates for the Super Structures strand (see **Strands**, opposite), i.e, build the longest bridge and/or the tallest tower. It's a fair bet that by the end of the workshop they'll have a gut feeling for triangulation, among other basic engineering concepts.

Figure 4: *Building the "longest bridge" at a Zometool middle school workshop, Denver, December 2012*

Another approach: you can simply pre-assign basic challenges by team, table etc. Such arranged marriages will also meet success. Any strand you choose will lead the students to real, exciting learning. Once the teams return to their tables but before they begin the hands-on work, explain to each team their challenge in detail, especially if you are using challenge cards (see **Teaching Resources**). Often participants don't read the Challenge Card and simply build the illustrations.

4.3 Address problems and facilitate learning -- At this point, begin the hands-on session. The first few minutes can determine the effectiveness of each team for the whole workshop. You may need to encourage, redirect or reconstitute them. In some cases, an individual or group may ignore the challenge altogether and go their own way. Treat these departurers with courtesy; much learning may occur in such a context.



...and beyond

With vigorous protests, students leave their models every 20 minutes to review, discuss and refocus attention. One at a time, have each team explain their challenge and what they are learning. Facilitate discussion with open-ended questions, and encourage teams to applaud each others' efforts.

4.4 Strands -- starting at the bottom of the page, this chart illustrates a few of the ways you can use your students' initial explorations and observations about the Zometool to guide them to exciting and profound discoveries. Their models get bigger and more beautiful, even as their minds are: they are experiencing math you can feel -- *quantum math* -- the mother of all maths, queen of the arts and sciences.

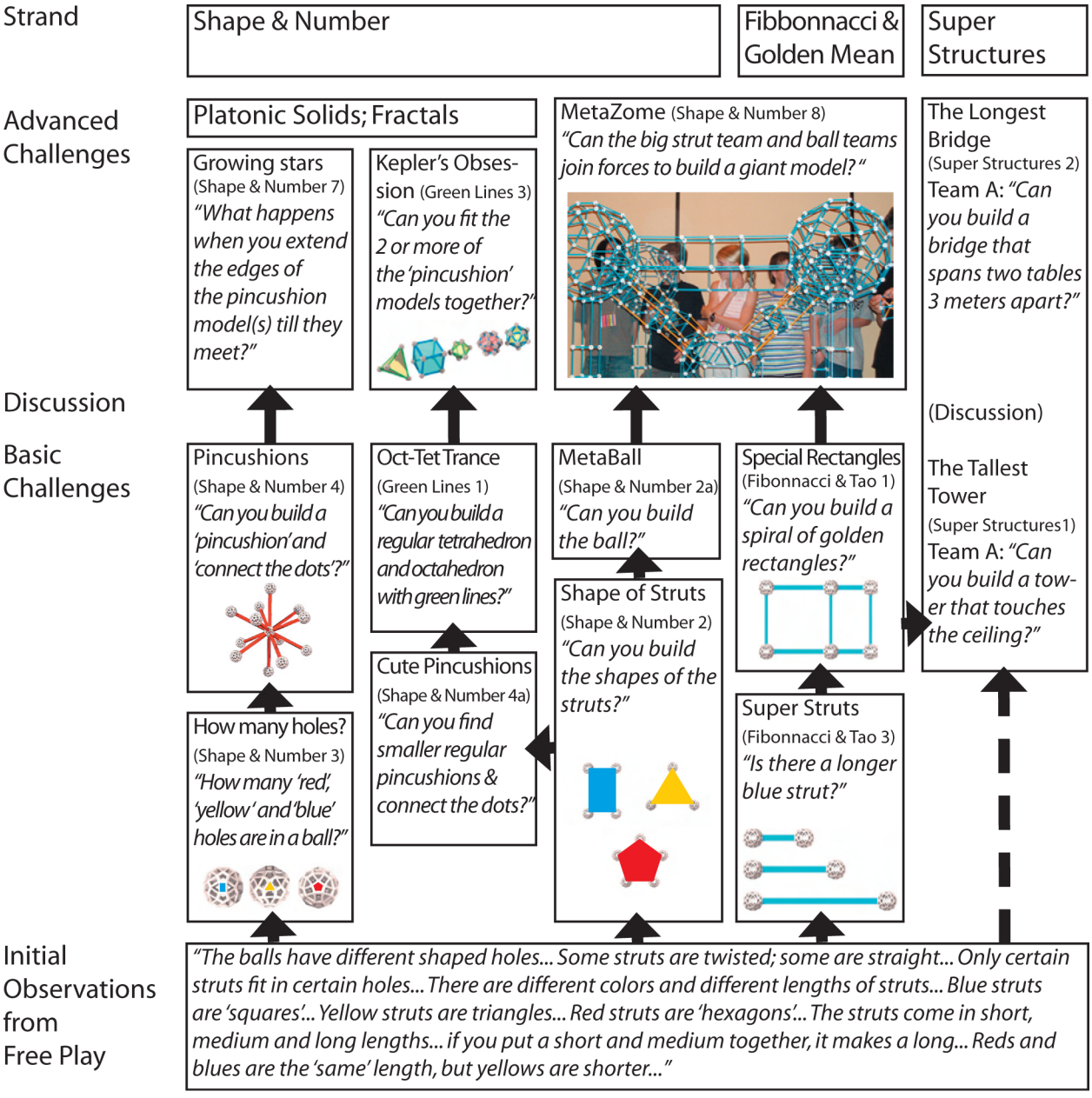


Figure 5: *Some possible strands showing how basic challenges build to more advanced explorations (the chart progresses from bottom to top.) Green Lines (Oct-Tet Trance & Kepler's) available separately*

4.4 Closing the workshop -- Use the same discussion format after the final session. Often participants are exuberant about their work and will want to show it off to friends, parents, take photos, etc. Use this enthusiasm to reinforce the learning that has taken place. Draw parents into the excitement when they arrive.

Despite the pain of disassembling their creations, participants must clean up. Remind students of the rule, "Take it apart, don't break it apart," so that the next workshop participants can have as much fun as they did.

5. Example: the Metazome Challenge Strand

A basic challenge ("Build the shapes of the struts;" see page 1) can lead to profound results. To start the initial discussion, you can ask, "so what do you know about Zometool so far?" Trevor: "The struts are different colors and different shapes." You repeat: "The struts are different colors and different shapes. What are the different shapes?" Diana: "Triangles, squares and hexagons." You: "Triangles, squares and hexagons. Does everybody agree with that?" Students: (general agreement, with some dissenters.) You: "Most people agree, but not everybody. Who doesn't agree? Why not?" Julia: "The blue struts are rectangles, not squares." You: "The blue struts are rectangles, not squares. Does everybody agree with *that*? O.k., what else? How many sides does a hexagon have?..."

So you challenge Julia and her team to build the shapes of the three struts. After the discussion you meet with the team, answer questions, and encourage them to walk around and see what other teams are doing if they get stuck. They build the Golden Rectangle quickly but stumble on the equilateral triangle and regular pentagon. The team at the next table is building red, yellow and blue "pincushions," and discover triangles and pentagons quite effortlessly when they "connect the dots" (see Figure 3.) Soon Julia's team trium-

phantly bids you back to their table. They're ready for the next step in the challenge: "Great! Now can you use your rectangles, triangles and pentagons to build a Zome ball?"

They dive in. You notice that they are struggling with 5 rectangles around a pentagon, and ask if the pentagons look the same on either side. Diana notices that the blue struts seem to "dish" inward on one side but outward on the other. In 20 minutes they have two whole Metazome balls. "I wonder... could you build a giant blue strut to connect these two balls?"

The rest is history. After their presentation, you challenge them to build a Metazome Atomium (pictured in Shape and Number 8) and suggest they join forces with the "Super Struts" team. This team recently discovered that super long struts using any two consecutive lengths (short/medium or medium/long) based on Fibonacci numbers (i.e., 1 long + 1 medium, 2 longs + 1 medium, 3 longs + 2 mediums, 5:3, 8:5, etc.) The session passes quickly. Parents are invited to the final presentation and are already snapping photos of the proud members of the Metazome construction crew and their creation.

6. Conclusion

This workshop is a great way to get started teaching with the Zometool. As you become more familiar with it, it's likely you will increasingly find applications for the Zometool in the classroom. You can also schedule follow-up workshops at regular intervals to reinforce and "hardwire" the new learning.

7. Teaching Resources

All resources are available for free at http://www.zometool.com/Resources (many are in "Resources for Teachers"), except as noted

1. Zometool Challenge Cards (K-12)-- 24 illustrated "discovery learning" challenges written for use in Zometool workshops (included with your Workshop kit, also in "Resources for Teachers")

2. Zometool Lesson Plans 1.0 (K-12) -- Standards-based lesson plans written by teachers for teachers

3. Zome Geometry (11, 12 & beginning college) -- supplementary textbook by George Hart and Henry Picciotto

4. Dr. David Booth's Zometool teaching materials (6-12) -- Educator and mathematician David Booth's deep and refreshing Zometool teaching methods were forged in the classroom, which he summarized in several books

4. Zometool Model Gallery (all levels) -- 3D models from instructions for System and Project kits (zometool.com/models)

5. All kit instructions -- PDFs of printed instructions for virtually all Zometool System and Project kits

6. vZome software -- virtual Zometool software available in web and desktop versions (also availabe at vZome.com)

7. Zometool Learning Adventures (K-8) -- Middle school students engage in 3 standards-based challenges in several short videos (access through our YouTube channel, https://www.youtube.com/zometool)

Notes and References

1. National Council of Teachers of Mathematics (NCTM) standards as addressed by Zometool are summarized in an appendix to Zometool Lesson Plans 1.0, pp. 201-208, 1998

2. Science, Technology, Engineering, Art and Mathematics: the Zometool integrates these like no other manipulative

3. The Boyer Commission on Educating Undergraduates in the Research University, REINVENTING UNDERGRADUATE EDUCATION: A Blueprint for America's Research Universities, 1998

4. No one "knows it all." The Zometool has informed the work of several Nobel Prizewinners, but when it comes to making new discoveries with the Zometool, your students are on a level playing field with these experts.

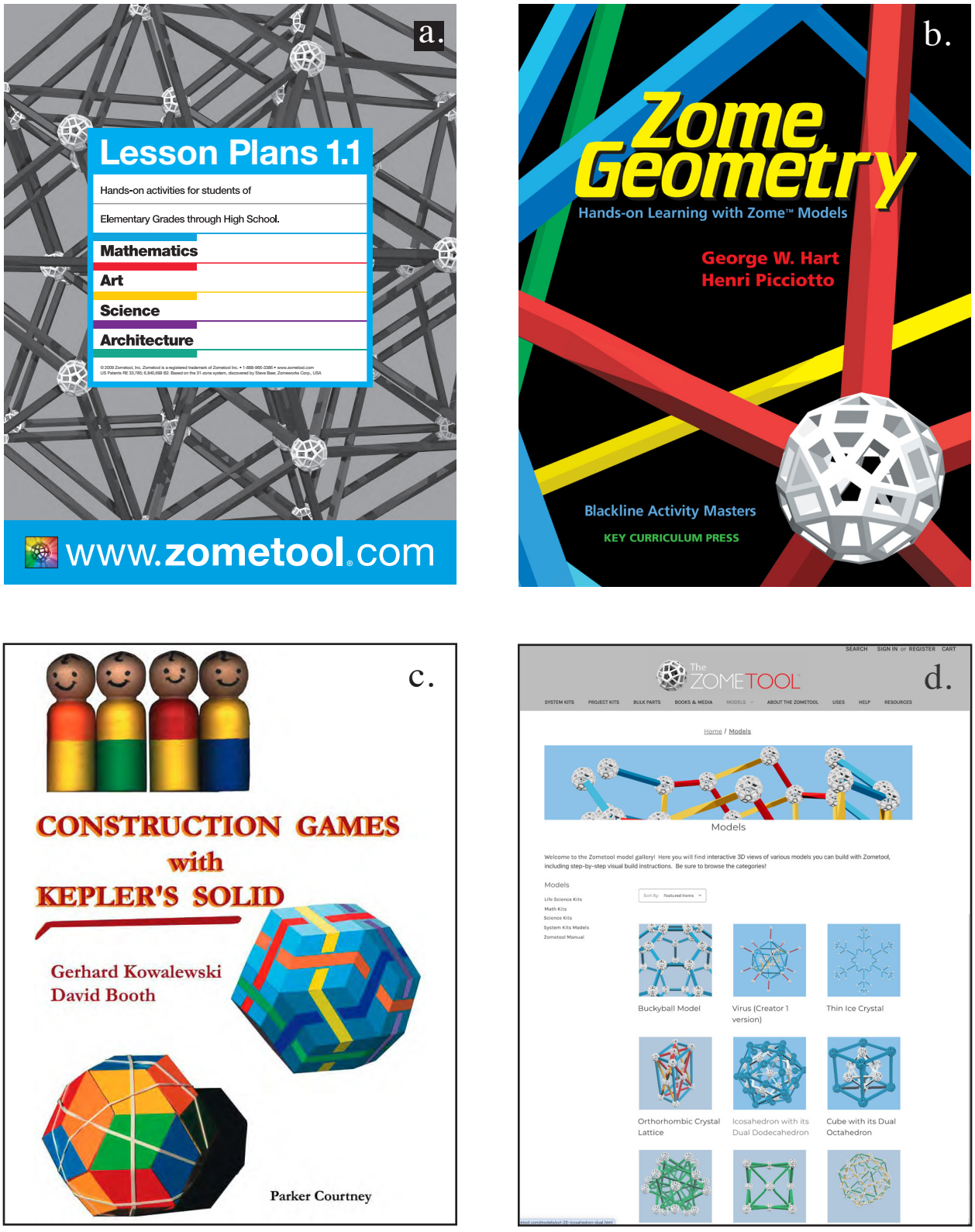


Figure 6: *Some of the free resources available at zometool.com: (a) Zometool Lesson Plans, written by teachers, for teachers (K-12), (b) Zome Geometry, for high school and college students, (c) one of several books by mathematician / Waldorf school teacher Dr. David Booth, and (d) the Zometool Model Gallery*