doi:10.2533/chimia.2023.789

Chimia 77 (2023) 789–791

Scientific Crocheting - A Proposal

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Abstract: This article draws an unconventional bridge between the art of crocheting and the intricate world of chemistry. Crocheting can serve as a tactile model for understanding chemical synthesis, structure and emergent properties, with parallels between the manipulation of crochet patterns and chemical codes. The aim is to nurture what we need most in next-generation scientists: confronting the unexpected, creativity and curiosity.

Keywords: Chemistry education · Nanographene · Research-context · Scientific crocheting · Tactile modeling

Have you ever encountered the following small-talk scenario?

"What do you do for a living?"

"Well, I am doing research in chemistry."

"Oh wow, I hated that in school…"

Sounds familiar? Likely it does – many of us who have studied chemistry have encountered this scenario at least once in our lives. In my experience, chemistry is often perceived through a narrow lens, as a profession of "breathing fumes, making stuff go bang, and risking cancer." Anyway yes, frankly, I remember with fondness my days as co-organizer of the experimental lectures at the University of Basel (the infamous *Sprengvorlesung*) where we blew the heads off teddy bears past Professor Constable's office. All in the name of science (outreach) of course. But. The public view is clear and does – in my opinion – relate back to how we have been exposed to chemistry in our primary education: by an archetypal chemistry teacher or professor (you know *exactly* what I mean) doing experiments with – at best – an explosion. Phenomena were front and center, with us copying observations from a simplified experimental setup. That has not changed much. Part of my time at UZH Zurich was spent setting final exams for budding chemistry teachers. Although didactically much has improved, the underlying principle of translating observation into law remains. If I told you I studied literature, you'd assume I write books. Engineering, you'd assume I build machines. Chemistry? You'd probably assume I still observed stirring solutions and made things blow up. It's challenging to break away from this entrenched view of chemistry as primarily deductive.

One must consider the contrasting daily routine of that same chemistry teacher when they were actively engaged in research. At the core of their work is the act of creation, particularly for synthetic chemists.

This leads me to question whether our current approach to teaching chemistry aligns with the essence of the discipline. We certainly need a keen eye and the ability to discern the extraordinary in the ordinary ("to see a world in a grain of sand" as William Blake puts it[1]), but my personal journey into chemistry really began when Professor Giese explained on the University's Open Day how the removal of a carbon atom from ethanol transforms it from having a good time to death. Chemistry, I would argue, is first and foremost a craft. Not just to observe, but to solve, create, change and evolve.

Now, how can we infuse this creative and hands-on approach into early chemistry education? Rather than mislabeling research as an extrapolation of observations, we should add elements of creation to it. For that, I believe we can draw inspiration from the creative arts. Art seeks to provoke and inspire through acts of creation after all and indeed I find the same is true of chemistry.[2] Simply consider Woodward, probably the most prolific chemist of the 20th century. A collection of his most famous papers is aptly titled 'Robert Burns Woodward: ***Architect*** and ***Artist*** in the World of Molecules'.[3]

When people think of art in the context of chemistry, they often imagine painting. I certainly did. Indeed, chemistry possesses a potent visual language, with widespread implications.[4] But it does go beyond the two-dimensional plane. As a more meaningful artistic representation of chemical research, I believe sculpting surpasses painting. After all, how often do we build molecular models and find ourselves captivated by their representation when we hold it in our hands? Probably a lot more often than by the brown sludge in our flask. However, not all forms of sculpting lend themselves equally to the representation of chemical research. For instance, pottery or woodworking represents more top-down engineering than the bottom-up construction intrinsic to chemistry. The allure of chemistry lies in the sequential transformation of constituent units into a larger composite.

One of my lab's primary research interests revolves around non-planar carbon lattices. It is now well understood that the introduction of structural defects, such as rings of atoms smaller or larger than the conventional hexagonal configuration into a graphene lattice invariably induces curvature and deformation within the structure. An excellent example is shown in Fig. 1.[5] The introduction of a seven-membered ring into a regular graphene lattice, *i.e.* expansion of a single six-membered ring by a single carbon, fundamentally buckles the system into a three-dimensional form.[6]

Synthesizing and studying contorted molecules is an excellent approach to discovering the relationship between chemical code, order, and how structure relates to property. Cutting-edge research whose essence can be very well represented by the simple art of crocheting. Let me explain. Hyperbolic or non-Euclidian spaces is the mathematical field underpinning warped graphenes. Mathematician Daina Taimina introduced crocheting to visualize hyperbolic discs as a means to make mathematical principles tactically accessible, to great success.[7] Because remarkably, crocheting exhibits an analogous phenomenon of strain-induction. Altering specific parameters can prompt the crocheted lattice to deviate from its planar configuration. While the underlying code differs from that governing graphene, the fundamental principle

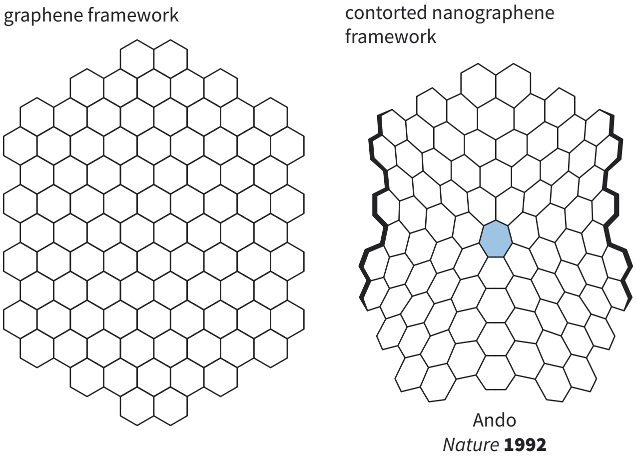

Fig. 1. Ring expansion by a single carbon induces curvature in graphene lattices (only framework shown).[5]

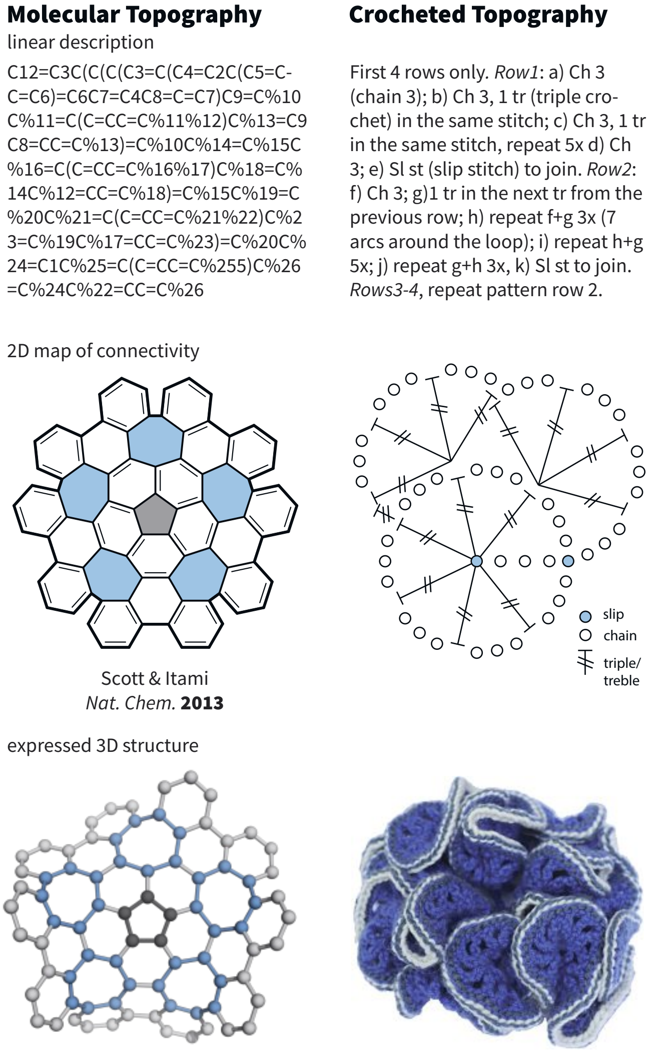

Fig. 2. The visual languages of chemistry and crocheting.

remains the same. We can devise sequences of crochet stroke operations that consistently yield the same topography. Likewise, altering the code inevitably results in a different structural outcome. Like a protein, the resulting lattice has a secondary structure determined by the 'atomic' code that underpins it. Code has been translated into structure. Proficiency in coding and decoding enables us to craft any desired structure. However, similar to proteins, tertiary considerations come into play – elements that are far away on the strand of code suddenly get close together in space with consequences for the expressionable superstructure.

We can make use of this approach to first demonstrate how an underlying code determines a three-dimensional structure, in analogy to a network of bonds. In Fig. 2, a warped graphene as introduced by Scott and Itami[8] is contrasted by Trnkova's hyperbolical, triangulated crochet-flower.[9] In both cases we can describe the connectivity of the code as a string or strings; there is no truncated code for crocheting (yet), but exists as an abbreviated verbal formalism. In this linear view, we learn which node connects to which neighbor in which fashion. We can identify bond orders and types and valency of each node. Describing the same system as a scheme gives us a visual reference of the structure. In crocheting, we make use of diagrams in much the same way as a classical chemical scheme. In 3D space, we can observe how the emergence of strain contorts the structure into a stable ground state. It is clearly evident how closely crocheting relates to how we approach nanographenes as chemists.

What I find particularly captivating is that the crocheting code can not only be described as an algorithmic sequence (*i.e.* like a SMILES string) but that it enables for intentional and spontaneous alterations. The consequences of such synthetic changes in code may not be immediately visible but materialize as the lattice expands. The topology of the crocheted surface is relatively complex, with a thread undulating to form stitches and reconnecting to the preceding row by passing again through the same stitches. The crocheted surface emerges through the interplay of these stitches, which makes it challenging to predict the resulting structure (or *vice versa* to infer the underlying code for a given object), although computational efforts seem fruitful.[10] Important for our scientific crocheters here is: Through acts of creation, we discover empirically the fundamental rules governing the construction of progressively intricate structures. Does this not resonate with the essence of synthesis? Indeed, it does, for it is precisely that. With it, we have entered a model space analogous to that of chemical research. Because the model can be quickly changed and is cheap, it enables a vast exploration and can yield entire textile ecosystems.[11] The art form elegantly mirrors how we, as chemists, approach research. With an idea and lots of trial and error. And it teaches us about emergence, a phenomenon that results from the collective of component parts and the serendipity that is associated with it.

This tactile approach yields insights not only into code manipulation and emergent expression thereof but also into material selection. For instance, crocheting with wire yields a very different synthetic experience and emergent properties than crocheting using yarn, or cooked spaghetti, for that matter. These variations are perceptible, open to exploration, modification, and amalgamation, thereby inherently nurturing curiosity.

Crocheting is easy to learn and budget-friendly – unlike research. The relationship between the joy of synthesis, creation, and exploring the crochetable space feels genuine to me. Imagine if students were introduced to chemical research through crocheting—how might our scientific landscape change?

Received: October 6, 2023

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