JOURNAL OF CHEMICAL EDUCATION
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A Mailman Analogy: Retaining Student Learning Gains in Alkane Nomenclature

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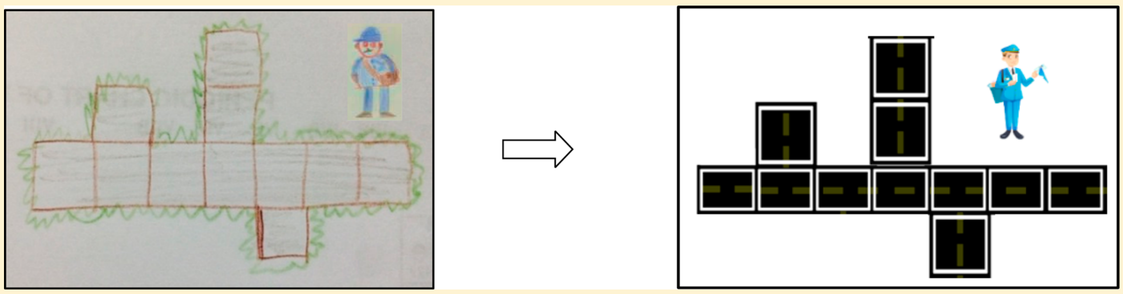
Supporting Information



ABSTRACT: Visual analogies play an important role in the teaching and learning of many diverse topics in chemistry. Organic nomenclature is an essential skill needed for student success in organic chemistry; however, it is a topic most students have difficulty in mastering. Without a strong foundation of nomenclature, students will struggle to follow more advanced organic chemistry topics. The project described uses the analogy of a mailman, who is new to an area and trying to remember the destinations of his postal route, to teach alkane nomenclature. Once students master the topic of alkane nomenclature, they are ready to take on the task of naming other organic molecules. Application of the Teaching-With-Analogies (TWA) model defines a stepwise approach to generate an effective analogy and hence was used in the development of the mailman analogy. An easily understandable picture of a mailman, a route system, and housing along the route provides an analogy capable of developing students' understanding of alkane nomenclature in organic chemistry. The assessment of student learning gains was performed in two different settings (Analogy versus Nonanalogy Groups) and it reveals that students who learn nomenclature with the analogy retain their learning gains through the course, whereas students who learn nomenclature without the analogy lose some of their gains as the semester continues.

KEYWORDS: *Analogies/Transfer, Pedagogy, Alkanes/Cycloalkanes, Nomenclature/Units/Symbols, Organic Chemistry*

■ INTRODUCTION

Organic chemistry is considered one of the most *challenging* courses in the college core curriculum, and many students enter organic chemistry courses with preconceived doubts about their ability to be successful. To bridge the gap between prior knowledge and current understanding, visual analogies can be introduced in the early stages of learning organic chemistry.

Analogies play a significant role in scientific teaching and are used as tools for understanding abstract concepts.[1−9] An "analogy" by definition is a comparison of the similarity of two concepts, the familiar (analogue) and the unfamiliar (target).[10] By building connections between familiar and unfamiliar concepts, relevant analogies from daily life can help students learn new material and eliminate misconceptions.[10−14]

Analogies that result in instructional scaffolding are more effective to promote student learning than simple analogies.[11] Several examples in organic chemistry include the concept of resonance as it relates to visual analogies as diverse as cartoon characters such as Dennis the Menace and Charlie Brown; bagels; and Big Dog−Puppy Dog.[1−3] The nature of a square knot versus a granny knot is another powerful visual analogy for recognizing diasteromers;[4] a twig with leaves analogy was used to help recognize the parent chain in naming organic molecules.[5] Retrosynthesis in organic chemistry can be taught using a sautéed summer squash preparation analogy.[6]

Nomenclature,[15,16] that is, naming organic compounds, is one of the most important topics in organic chemistry. To be successful in organic chemistry, it is essential that the basics of naming molecules is mastered from the very outset. Failure to understand this topic often results in difficulty in understanding future material covered in the course and impedes the development of critical thinking skills needed for success in more advanced topics. As such, a mailman analogy, a visual analogy, was implemented to teach the topic of alkane nomenclature.

The Teaching-With-Analogies (TWA) model can be used to make science more meaningful to learners by promoting and building cognitive relationships between what is already known and what is being learned.[17,18] In the TWA model, concepts that are familiar (analogue) are used to build understanding of complex material that is less familiar (target) to deliver effective

Received: July 13, 2015
Revised: January 22, 2016

DOI: 10.1021/acs.jchemed.5b00551
J. Chem. Educ. XXXX, XXX, XXX−XXX

analogies.[11] In the mailman analogy, students are introduced to organic nomenclature of alkanes and, once comfortable with the analogy, are able to build on that framework to name more complex organic structures such as cycloalkanes, alkenes, and alkynes. (see Supporting Information.)

Because the rules of organic nomenclature are highly structured, the mailman analogy had to mirror that system. A mailman character, Dan, delivering mail according to defined criteria can be analogous to the rules in alkane nomenclature.

■ HOW THE ANALOGY WORKS

To name an organic molecule, three parts are required: the prefix, the parent chain and the suffix. The prefix constitutes *where* and *what* the substituents are; the parent chain is the longest chain; and the suffix represents the functional groups. The molecule to be named can be considered a subdivision made up of "lots." Some of these lots become roads or routes and others become destinations. In this analogy, the lots are referred to as blocks.

Every block (Figure 1) represents a carbon atom in the parent chain or in the substituents. The longest (parent) chain becomes the main route that mailman Dan takes and the blocks that are *not* part of the longest chain become destinations for mail delivery. Background information about mailman Dan is provided in the Supporting Information to keep the analogy simple and straightforward.

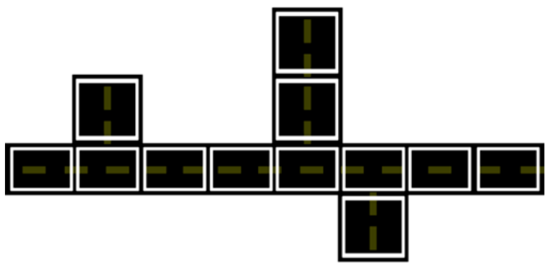


Figure 1. Every block represents a carbon atom for the molecule to be named.

Rule #1: Choosing the Longest Route = Finding the Parent Chain

First, Dan has to identify which blocks constitute the main route and which blocks are destinations. In order to best remember mailman Dan's new neighborhood, he chooses the longest available route. Dan follows the longest route because his supervisors have asked all the mail carriers to do so for consistency purposes. A route map with two possible longest routes is shown in Figure 2. Figure 2A has eight blocks and Figure 2B has seven blocks; mailman Dan chooses the eight-block route.

The route selected by mailman Dan is the longest contiguous path available, whether it is straight (Figure 3A) or bent (Figure 3B). Figure 3A and B represents two completely different "subdivisions" (molecules).

Rule #2: Blocks Not Part of Longest Route Become Destinations = Groups Not Part of the Longest Chain Becomes Substituents

Once the longest continuous route with maximum blocks is chosen, all the side blocks that are *not* on the longest route are converted to destinations (Figure 4).

Information on Destinations = Information on Alkyl Groups

The three different types of destinations (substituents) used in this analogy are shown in Figure 5: a single block is represented by a house; two blocks are represented by a duplex; and three blocks are represented by a three-story house.

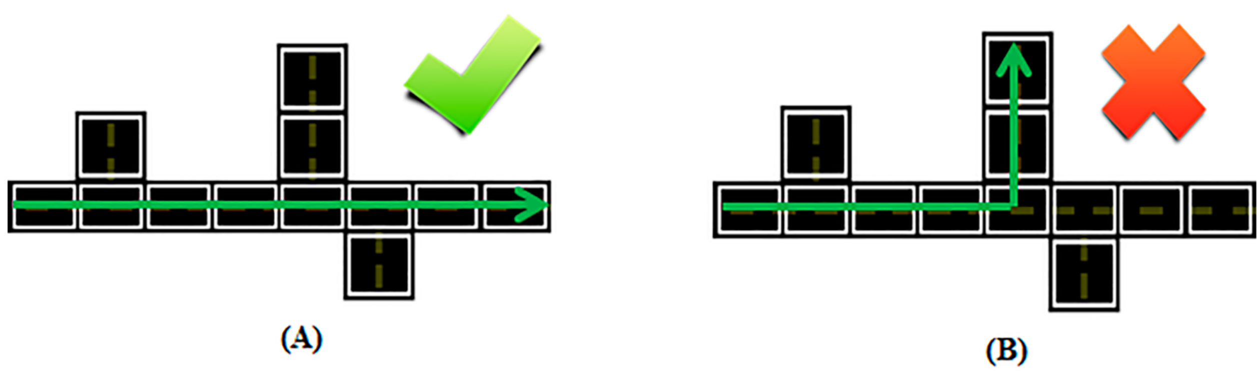


Figure 2. Mailman Dan chooses the longest block route, which is the eight-block route (A) and *not* the seven-block route (B).

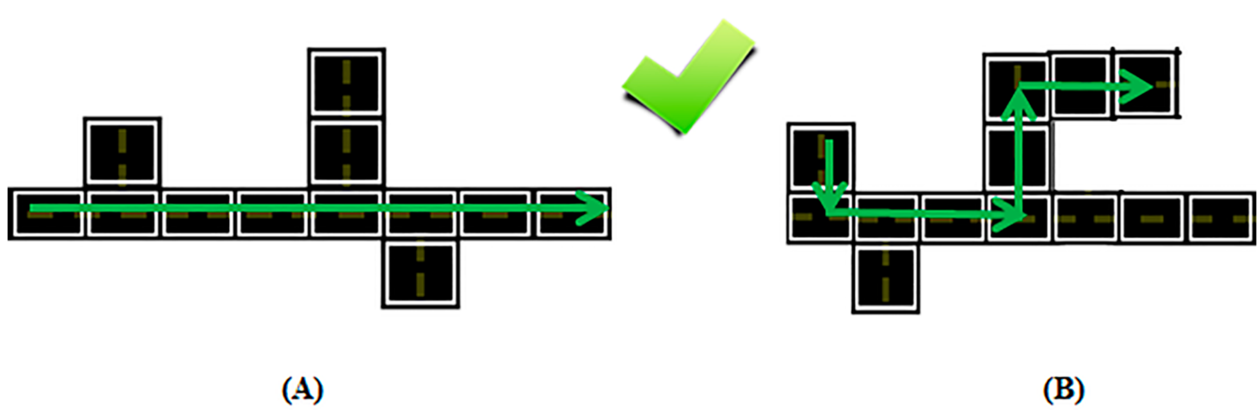


Figure 3. Mailman Dan chooses the contiguous path, whether is its straight (A) or bent (B).

DOI: 10.1021/acs.jchemed.5b00551
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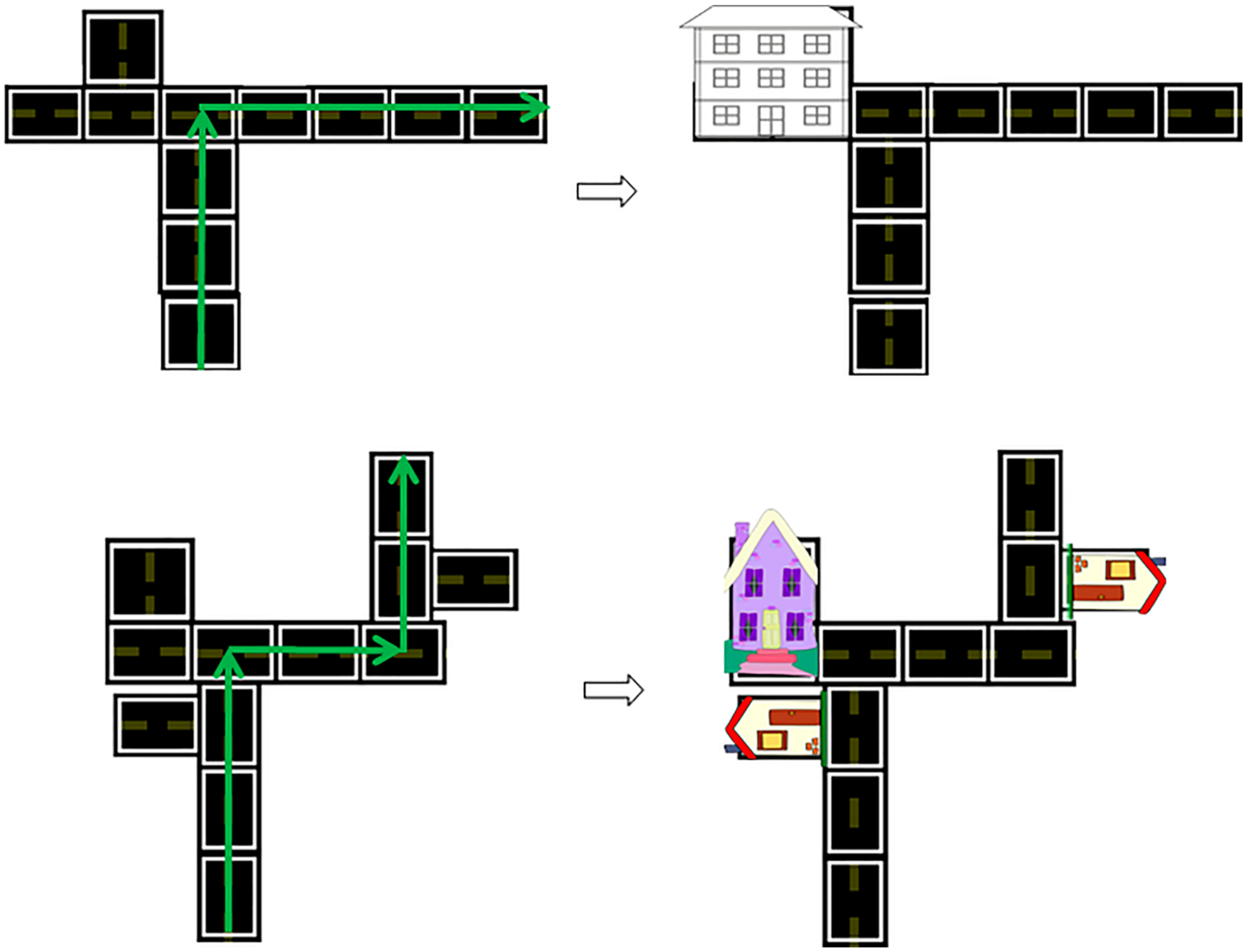

Figure 4. Mailman Dan considers all the remaining blocks as destinations after selecting the longest path.

Figure 5. Illustrating different types of destinations (substituents) corresponding to one, two, and three blocks that are not a part of the main route.

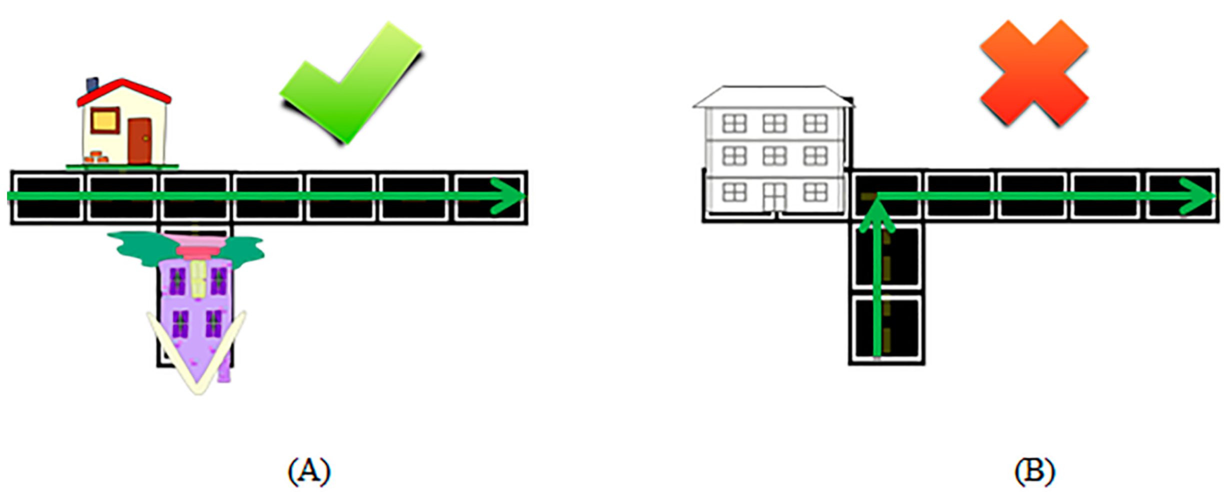

Figure 6. Mailman Dan chooses the route with maximum number of destinations on both sides of his longest route (A) rather than one destination (B).

DOI: 10.1021/acs.jchemed.5b00551
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Figure 7. Mailman Dan starts on the end closest to the first destination; the chosen route begins from the left end side since the house is positioned at the 2nd block rather than the 3rd.

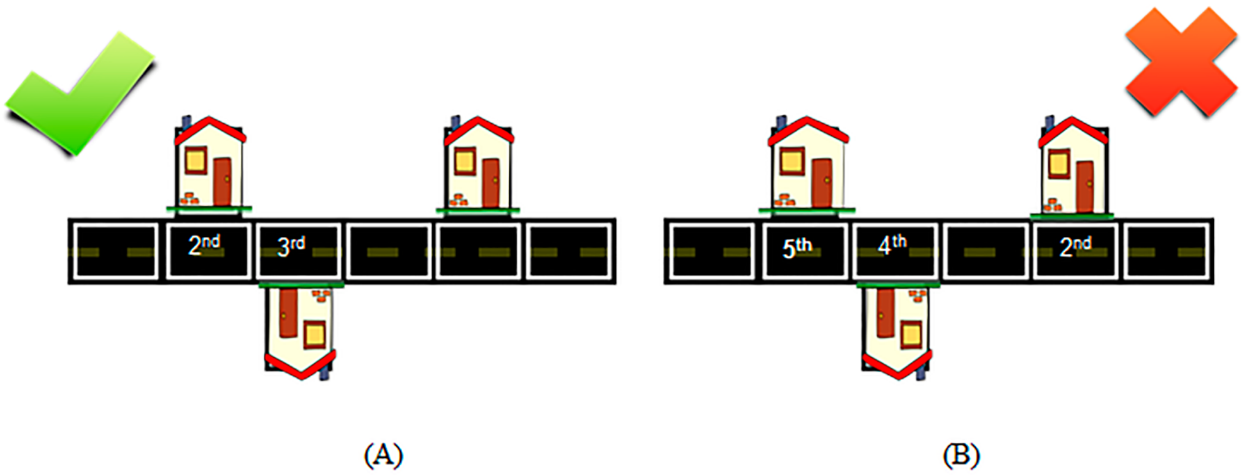

Figure 8. Mailman Dan chooses the route from the left end since the second destination is positioned closer at the third block in (A) rather than at the fourth block in (B).

Figure 9. Mailman Dan uses alphabetical order of the destinations when choosing between otherwise equal routes. D in duplex (A) comes before H in house (B).

Rule #3: Choosing the Longest Route Based on Destinations = Choosing the Longest Chain Based on Substituents

If mailman Dan identifies two possible routes equivalent in length, he chooses the route that results in the maximum number of destinations on either side of the route (Figure 6).

Rule #4: Determining from Which End to Start the Route = Numbering the Carbon Chain

Because mailman Dan's mail bag is heavy, he wants to lighten his load as soon as possible. He starts on the end of the route containing the first destination; therefore, the route will be numbered starting from the end nearest to the destinations (Figure 7).

Rule #5: First Destination at the Same Distance = First Substituent at the Same Distance

If the first destination is at the same distance from either end (i.e, numbered the same way from either direction), then he considers the second destination in the path (Figure 8). In Figure 8A, the destinations are positioned at the second, third, and fifth blocks,

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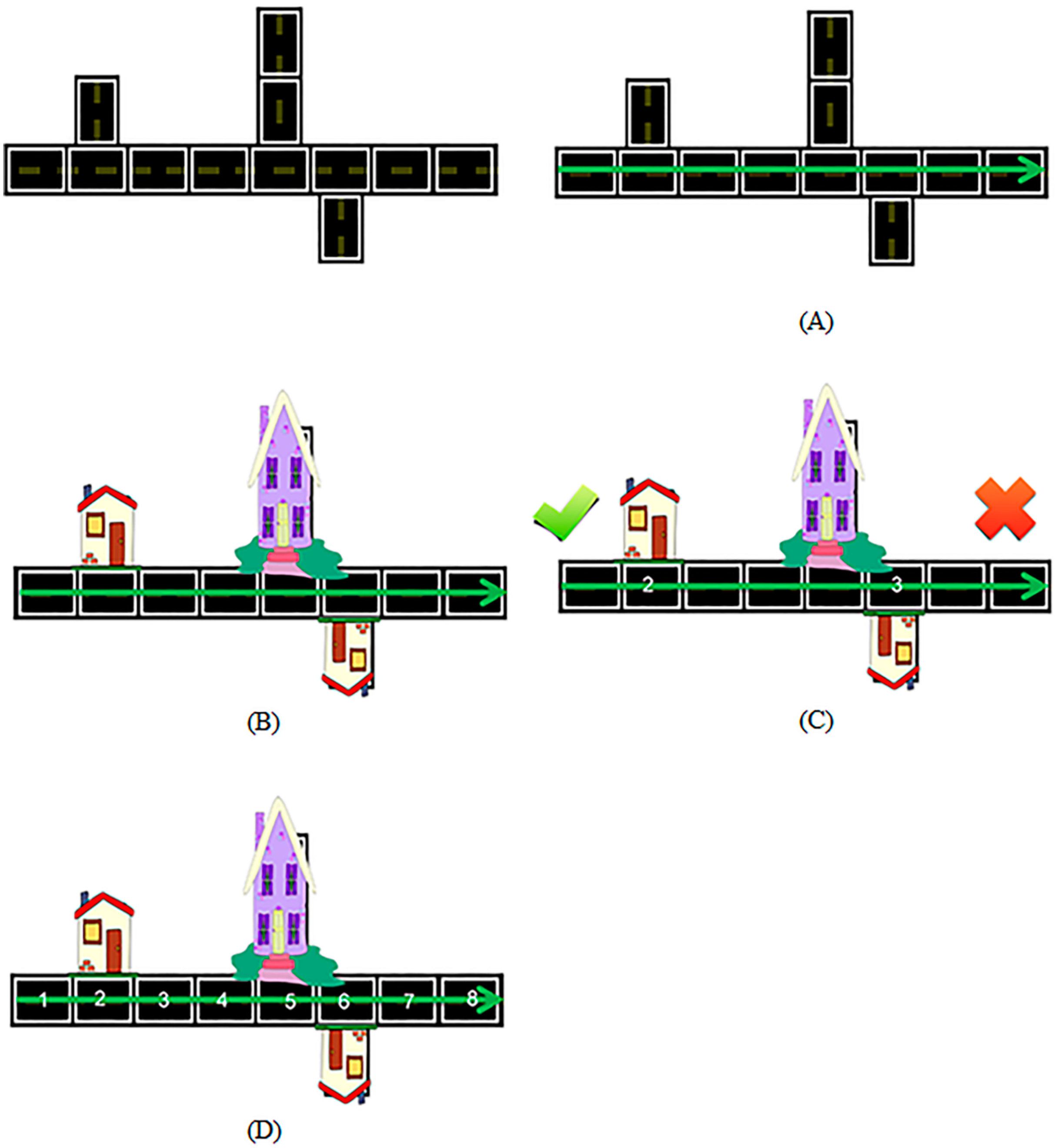

Figure 10. Worked example shows how to choose the destinations and direction of choice in a stepwise manner for **5-duplex-2,6-dihouseeightblockroute**.

whereas, in Figure 8B, the destinations are positioned at the second, fourth, and fifth blocks. Because mailman Dan wants to lighten his load sooner, Figure 8A is the correct choice of route.

Rule #6: Destinations at the Same Distance from Either Side = Substituents at the Same Distance from Either Side

If the destinations are placed on the same block on either side, then mailman Dan has to make a decision regarding which end to start his route. Because he is trying to remember the destinations on his route, he uses alphabetical order to break the tie. In Figure 9, a house and a duplex are the two choices of destinations for mailman Dan. In Figure 9A, a chosen path has a duplex at the third block and a house at the fifth block. In Figure 9B, the chosen path has a house at the third block and the duplex at the fifth block. Mailman Dan makes the choice based on the alphabetical order of the destinations, regardless of the size of the destination. To keep the analogy simple, each destination is assumed to have the same number of occupants. D—duplex comes before H—house alphabetically, so mailman Dan delivers first to the duplex, then to the house.

Rule #7: Remembering the Destinations on Route = Naming the Compound (Wrapping Up)

The complete analogy can be illustrated in an example shown in Figure 10. The longest, most direct path is chosen; in this case, an eight block route is selected (A), leaving three destinations: two houses and a duplex (B). He sees a house at the second and sixth block and a duplex at the fifth block. Mailman Dan starts closest to his destinations, so the route is numbered from left to right; the first destination at the second block is more desirable than the

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J. Chem. Educ. XXXX, XXX, XXX−XXX

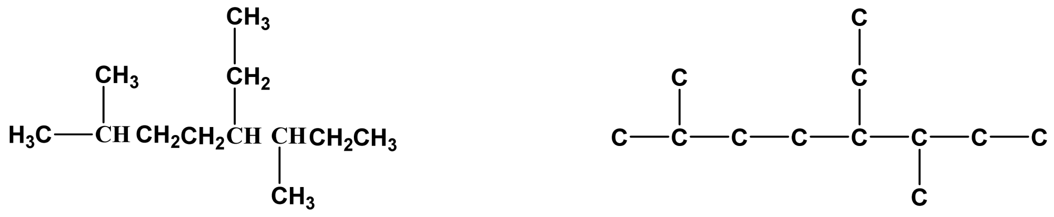

Figure 11. Expanded structure (A) and carbon backbone structure (B) of 5-ethyl-2,6-dimethyloctane.

first destination at the third block (C). When naming the compound, the destinations come in alphabetical order. The prefix *di* is used to indicate two houses and hence the resulting name is **5-duplex-2,6-dihouseeightblockroute** (D).

A student will see that the house represents the methyl group, the duplex the ethyl group, and the three-story house the propyl group. The alphabetical arrangement of the destinations matches the alphabetical arrangement of the corresponding substituents.

Students will already be familiar with the suffix -ane for alkanes and Greek prefixes for the numbers leading to the name: **5-ethyl-2,6-dimethyloctane.** See Supporting Information for the full comparison for naming **5-ethyl-2,6-dimethyloctane** using the classic nomenclature rules with the new visual analogy (Figure 11).

■ ASSESSMENT AND THE STUDENT LEARNING GAINS FROM THE ACTIVITY

The assessment of this activity was carried out over two semesters (fall 2013 and spring 2014) with full Institutional Review Board (IRB) approval. Two classes taught by the same instructor of Organic Chemistry I were invited to participate in the study. The study group (analogy group (AG)) learned nomenclature rules using the mailman analogy; the control group learned nomenclature rules using the regular lecture with power point slides (nonanalogy group (NG)). Data in the form of pre-/post-test quiz scores, exam scores and survey results were collected. The participant information, methods, procedure, questions (pre-/post-test and exams), survey, and the results of students' perceptions are incorporated in the Supporting Information.

The survey was administered to both groups (AG and NG) to evaluate student perceptions on the topic of nomenclature. The survey indicated that women reported higher levels of understanding and engagement in both groups as compared to men. The details about both groups for this study are provided in Supporting Information (under Student Learning).

To explore learning gains between pretest and posttest, and Exam one and the Final Exam, the normalized learning gain[19] was computed for each student for each pair of tests. The normalized learning gain $\langle g \rangle$ was computed as

$$\langle g \rangle = \frac{(\text{Final Exam Score} - \text{Exam 1 Item Score})}{(\text{Maximum Item Score of 12} - \text{Exam 1 Item Score})}$$

For the pre-/post-test equation, post-test replaced "Final Exam Item Score," pretest replaced "Exam 1 Item Score," and the "Maximum Item Score" was changed to six. Normalized learning gain (NLG) analyses are important for four reasons: (a) they remove from the sample all students who scored 100% on the pretest or Exam 1 Items (respectively) and thus could not demonstrate any additional learning, (b) they remove from the sample all students who scored lower on the posttest or Final Exam Items and "backslid" in their learning, (c) they more accurately estimate improvement over time by controlling for ceiling effects, and (d) they are robust even when students guess on multiple choice items.[19] If the NLG is multiplied by 100%, the results can be interpreted as the percentage of relevant material unknown at pretest or Exam 1 that was learned by post-test or the Final Exam (respectively).

From pretest to post-test, students in both groups significantly improved with no difference in magnitude between them (details provided in Supporting Information), suggesting that both instructional methods are equally effective in promoting short-term learning gains on this topic. However, an independent samples *t* test revealed a significant difference in the magnitude of the NLG from Exam 1 to the Final Exam between the groups, $t(100) = -2.22$, $p < 0.05$, Cohen's $d = 0.45$. Those in the NG picked up 56% of the possible additional points they could earn; whereas those in the AG picked up 73% of the possible additional points. The primary reason for this difference was that 32% of the students in the NG scored lower on the Final Exam than Exam 1, whereas only 19% of the students in the AG scored lower on the Final Exam (Table 1).

Table 1. Normalized Learning Gain by Groups

	Total Sample	100% on Both Exams	Lower Score on Final Exam Items	Normalized Learning Gain (NLG)		
Groups	*n*	*n*	*n*	*n*	*M*	SD
Lecture	91	20	29	42	0.56	0.43
Analogy	97	19	18	60	0.73	0.34

These results suggest that the lecture method leads to a "backsliding" in learning, with many students who had previously demonstrated mastery losing the ability to retain and redemonstrate it. In contrast, the analogy method seems to both promote greater long-term retention among those who learned it when it was first taught and a greater delayed "aha" realization among those who hadn't mastered it by Exam 1.

■ CONCLUSION

The mailman analogy provides a novel and methodical approach for teaching the topic of alkane nomenclature, which is considered one of the most significant and foundational concepts in organic chemistry. The story utilizes a mailman character, Dan, to explain various rules through an elaborate visual analogy. His overall aim is to remember various destinations (houses and duplexes) in a new location, so he applies certain rules to remember his neighborhood, which are analogous to the rules used by the students to learn alkane nomenclature in organic chemistry. Students who learned the topic of nomenclature using the analogy were shown to retain their learning gains compared to students in the nonanalogy group.

DOI: 10.1021/acs.jchemed.5b00551
J. Chem. Educ. XXXX, XXX, XXX−XXX

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00551.

Development of the activity, Comparison between the nomenclature rules and the Mailman analogy, Teaching with Analogies model system, Information on the assessment of the activity and the Presentation Slides (PDF)
The power points slides with the mailman analogy (PDF)
Survey for Visual Analogy (PDF)
Survey for Nonanalogy (PDF)
Pre-test/Post-test/Exam 1 and Final Exam questions on Nomenclature Topic (PDF)

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors are grateful to Nazim Ali for drawing the initial figures of the mailman and houses. The financial support provided by the Department of Chemistry, College Office of Undergraduate Research (COUR), Honors Program at Georgia Southern University, and the Development of Instruction award are gratefully acknowledged.

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DOI: 10.1021/acs.jchemed.5b00551
J. Chem. Educ. XXXX, XXX, XXX−XXX