Semantic Reasoning in Young Programmers

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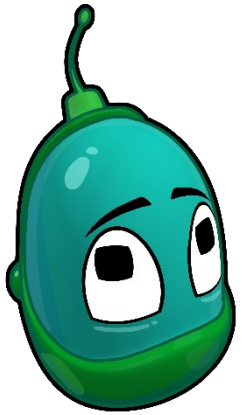


SIGCSE '17, Seattle, WA

Funded in part by a gift from Microsoft Research.

What Do Students Understand About Computer Programs?

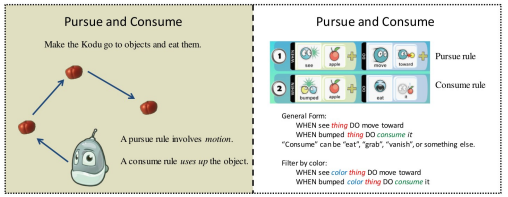
- Young students program by trial and error when they don't understand the meaning of the code they write.

- Can we teach students to reason effectively about programs?
  - Yes, if we use the right primitives (Kodu).

- Why would we want to teach that?
  - Students who can reason about programs should excel at writing and debugging programs.

How Can We Guide Students to Reason About Programs?

- Help them see **higher-level structure:**
  - Idiom catalog for common code patterns.
  - First idiom: Pursue and Consume



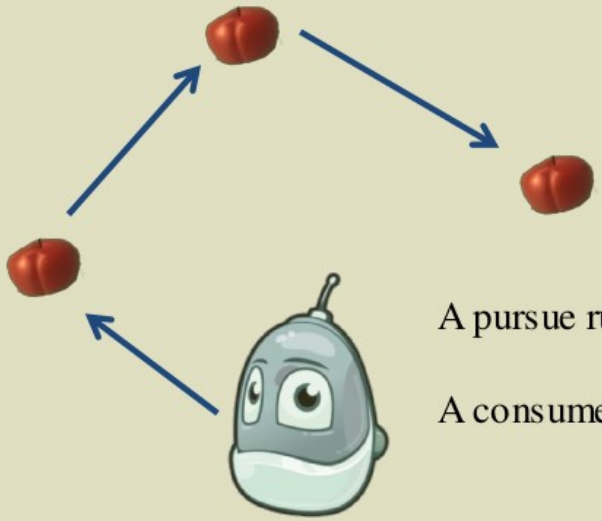
- Help them understand the **semantics** of the language they're using:
  - The “Laws of Kodu”

Challenge: these concepts must be expressible in ways that young children can understand.

First Idiom: Pursue and Consume

Pursue and Consume

Make the Kodu go to objects and eat them.



A pursue rule involves *motion*.

A consume rule *uses up* the object.

Pursue and Consume

Pursue rule

Consume rule

General Form:

WHEN see *thing* DO move toward

WHEN bumped *thing* DO *consume it*

"Consume" can be "eat", "grab", "vanish", or something else.

Filter by color:

WHEN see *color thing* DO move toward

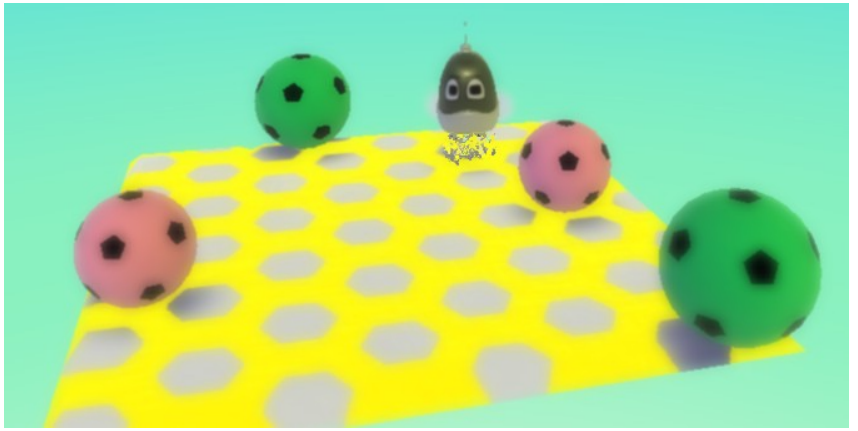
WHEN bumped *color thing* DO *consume* it

The Laws of Kodu

The First Law of Kodu governs conflict resolution in variable binding.

Pursue and Consume Problems

- A class of reasoning problems unique to Kodu.
- Test student understanding of both the idiom and the first three laws.
- Varying levels of difficulty.



- Diagnostic for certain common fallacies in naive Kodu reasoners.

The Study

- Participants:
  - Two groups of 19-20 third graders.
  - Had prior exposure to Scratch Jr., and were learning Scratch in school.
- Format:
  - Four 80 minute after-school Kodu sessions spaced 1-2 weeks apart
  - Written assessments on days 2, 3, and 4.
  - Group 1 in Fall 2015; Group 2 in Spring 2016. Same curriculum except:
    - Group 1: laws of Kodu taught **implicitly**.
    - Group 2: laws of Kodu taught **explicitly**.

Results Reported Here

I. Understanding standard Pursue and Consume.

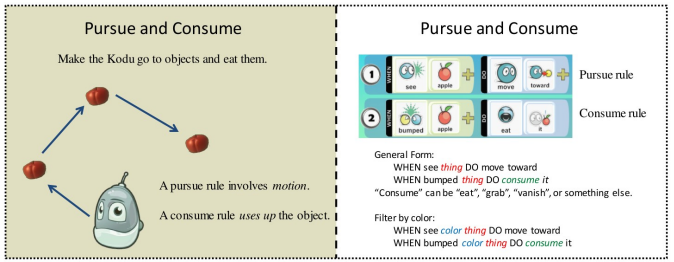
II. Understanding order of execution.

III. Understanding action conflict resolution.

IV. Reasoning about anomalous rule sequences.

I. Understanding Standard Pursue and Consume

- Students could:
  - Distinguish between pursue and consume rules.

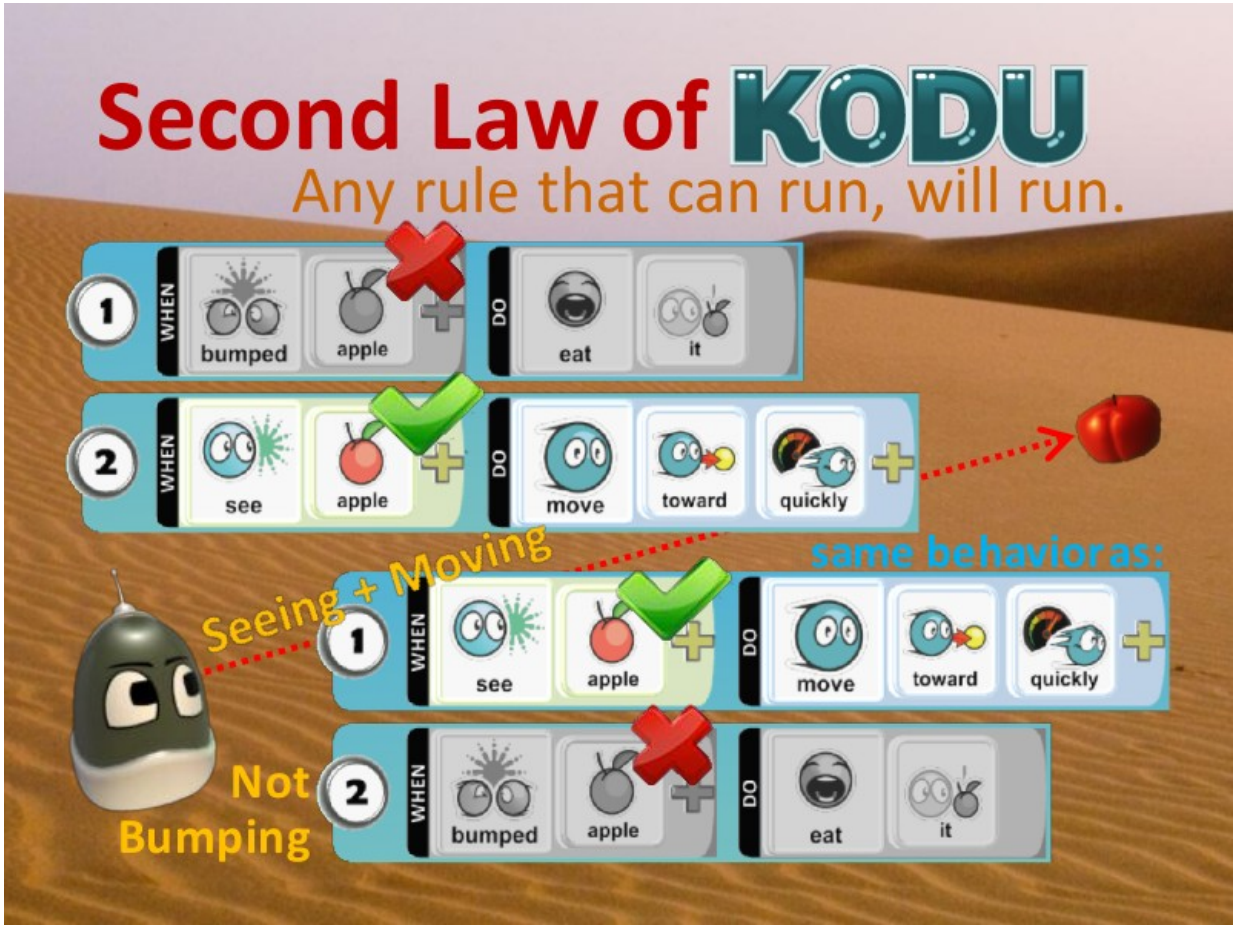


  - Recognize what category a rule was in.
  - Select the correct rule from three graphical alternatives given a verbal description.
  - Apply the First Law to determine which object would be pursued first.

  - Draw the trajectory the kodu would take to eat all the apples (evidence for mental simulation).

II. Understanding Order of Execution

Kodu rules can run in any order (Second Law).

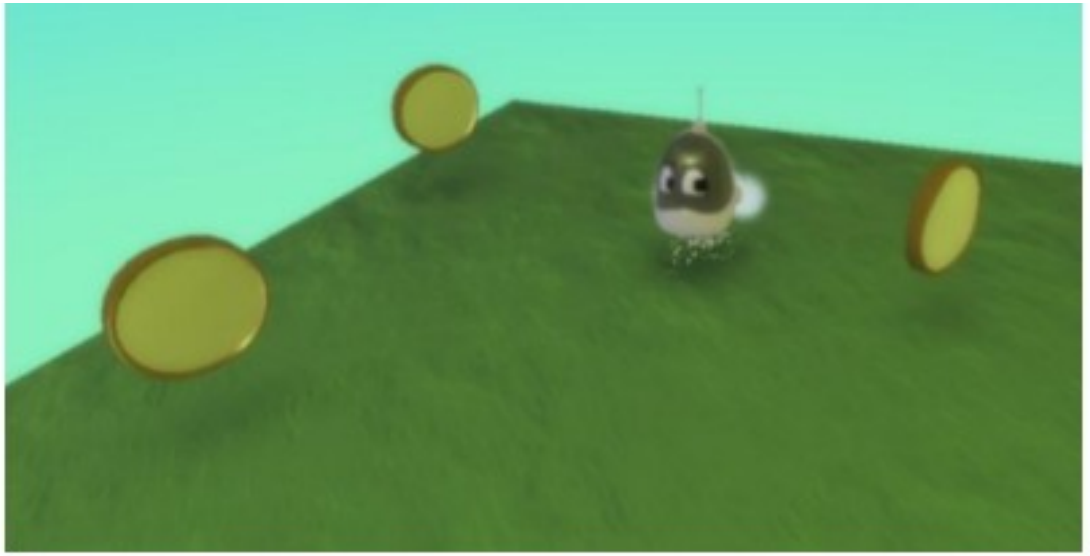


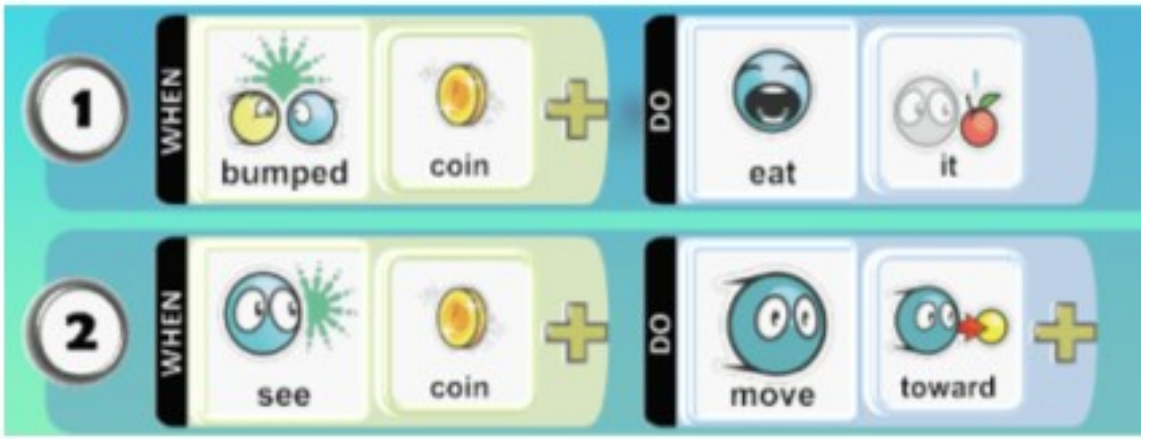
Misunderstanding Rule Ordering

Sequential Procedure Fallacy:

- Students think rules must execute in sequence.
- Possible negative transfer from Scratch, or from the sequential numbering of rules.

Module 1, Question 8





What will the kodu do in the coin world given the rules shown at left? Circle your answer:

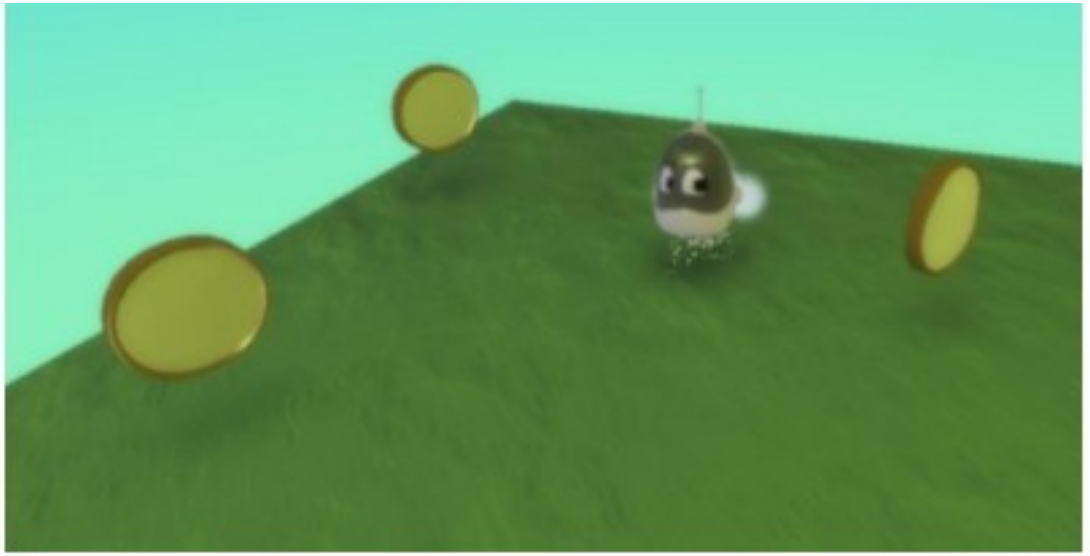
a. Sit around waiting for a coin to bump into it.

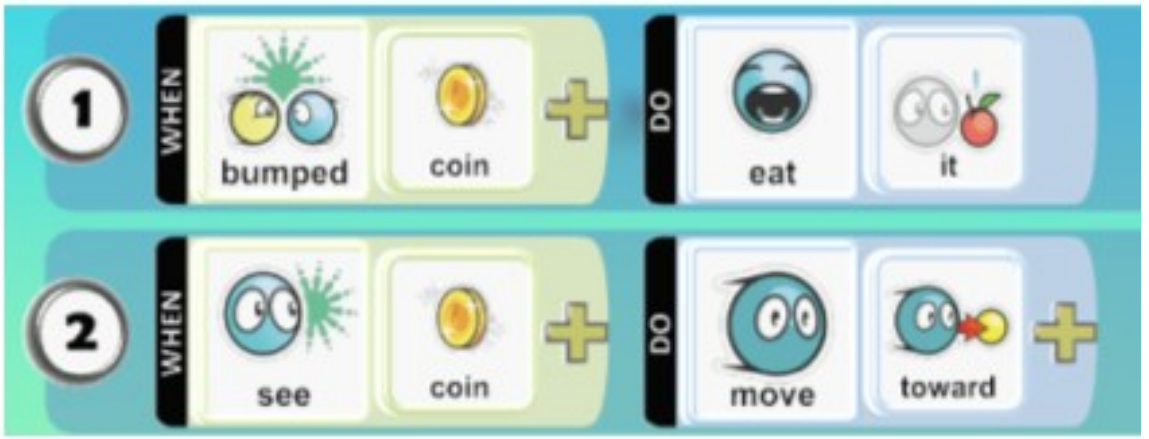
b. Eat one coin and then stop.

c. Eat all the coins; it doesn't matter that the consume rule comes first.

d. Go to the first coin and get stuck there.

Module 1, Question 8





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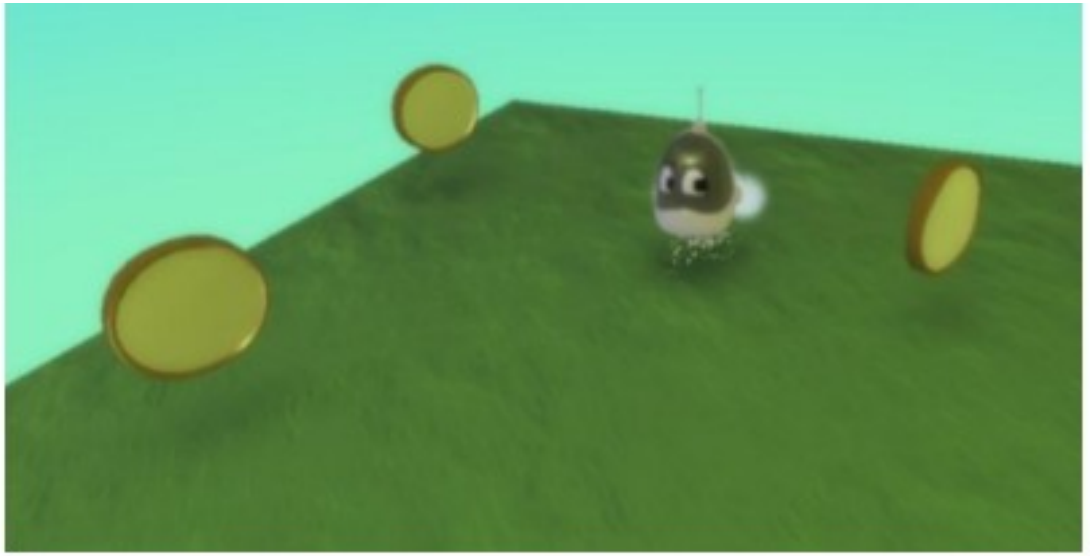
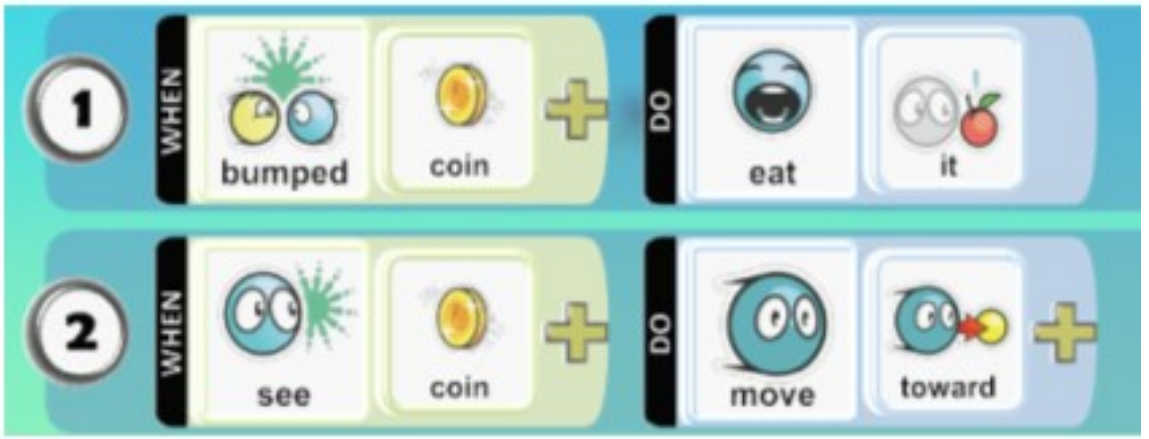
d. Go to the first coin and get stuck there.

✔ Correct Response ✖ Sequential Procedure Fallacy

Module 1, Question 8





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b. Eat one coin and then stop.

c. Eat all the coins; it doesn't matter that the consume rule comes first.

d. Go to the first coin and get stuck there.

✔ Correct Response ✖ Sequential Procedure Fallacy

Module 2, Question 10

What will the flying fish do in this world? Circle your answer.

a. Eat one starfish and then stop.

b. Eat all the starfish. The order of the rules doesn't matter.

c. Go to the nearest startfish and get stuck there.

d. Sit around waiting for a starfish to bump into it.

✔ Correct Response ✖ Sequential Procedure Fallacy

Rule Ordering Results

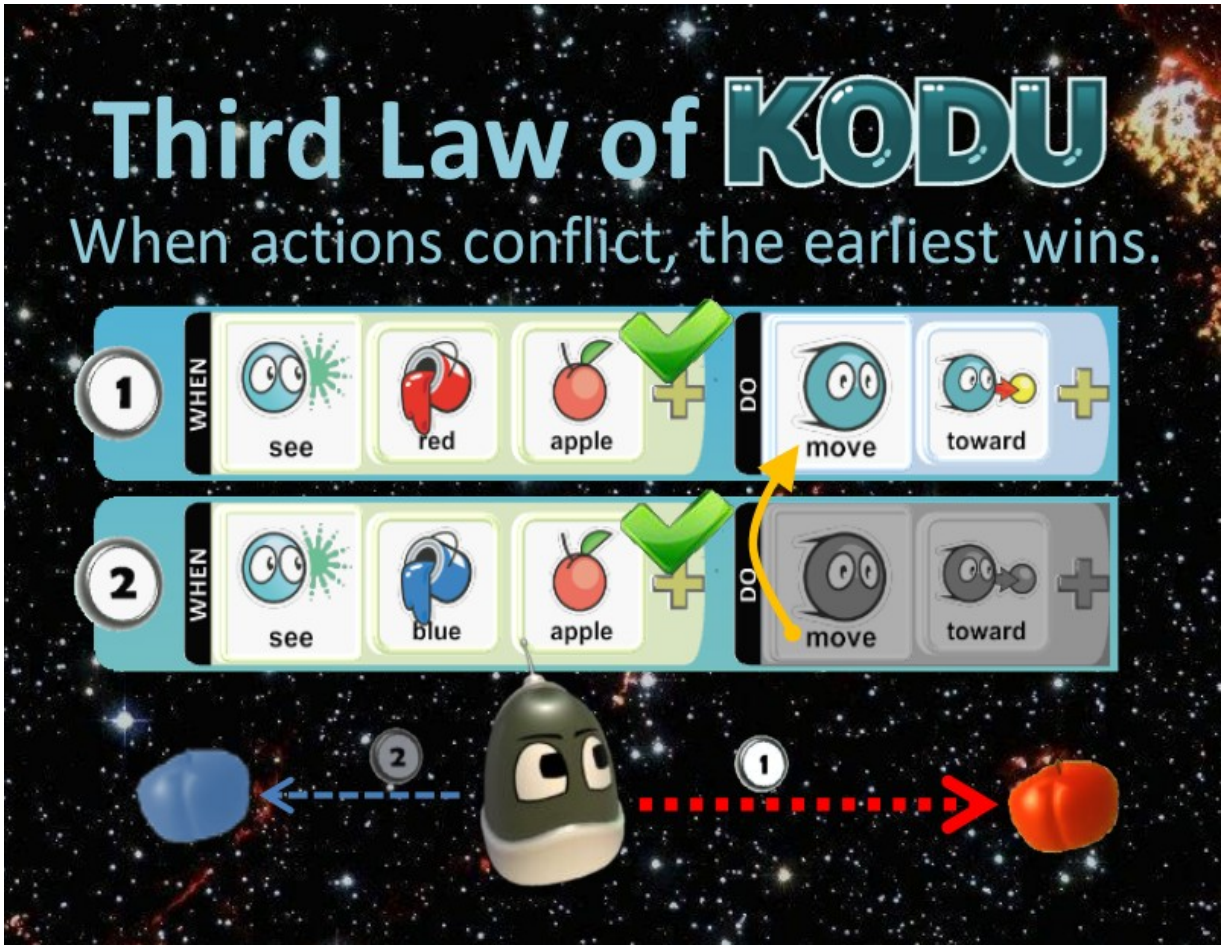
Problem	Group	A	B	C	D	Total
M1Q8	Camp 1	11	0	**9**	0	20
	Camp 2	1	0	**17**	0	18
M2Q10	Camp 1	1	**11**	1	7	20
	Camp 2	2	**16**	0	1	19

✔ Correct Response ✖ Sequential Procedure Fallacy

Camp 2 (89% correct) outperformed Camp 1 (50% correct).

III. Conflict Resolution

When there are two pursue rules, a conflict arises. What to pursue first?



Misunderstandings About Conflict

Collective Choice Fallacy:

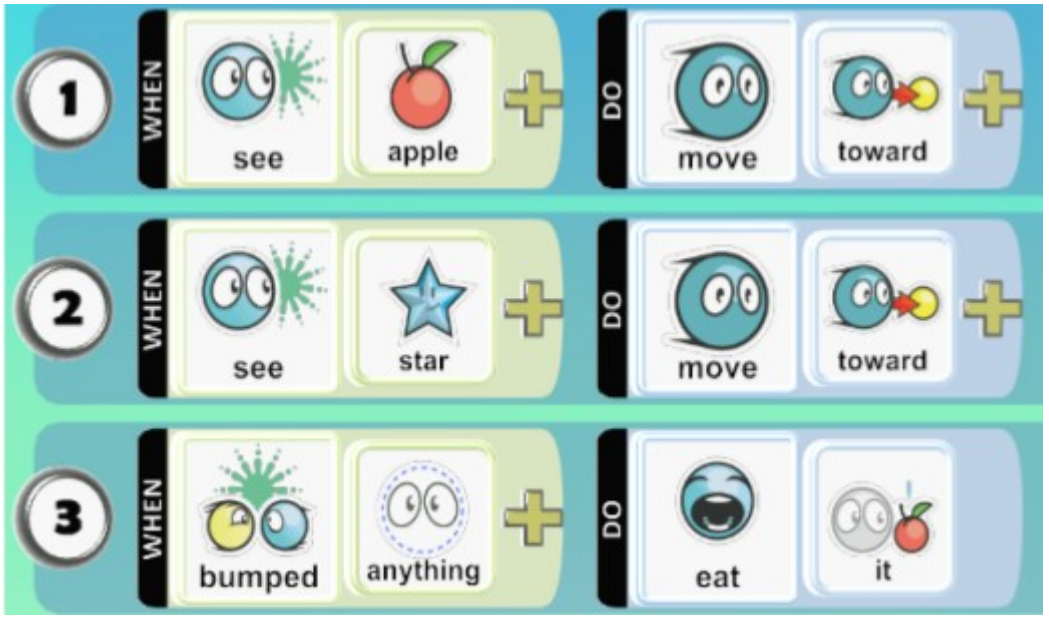
- Some students think that rules *collectively* choose a closest object from among all potential matches for any rule.

Sequential Procedure Fallacy: as before.

Misapplication of the Third Law:

- Not realizing that rule conflict ends when the first pursue rule can no longer run.

Module 1, Question 9



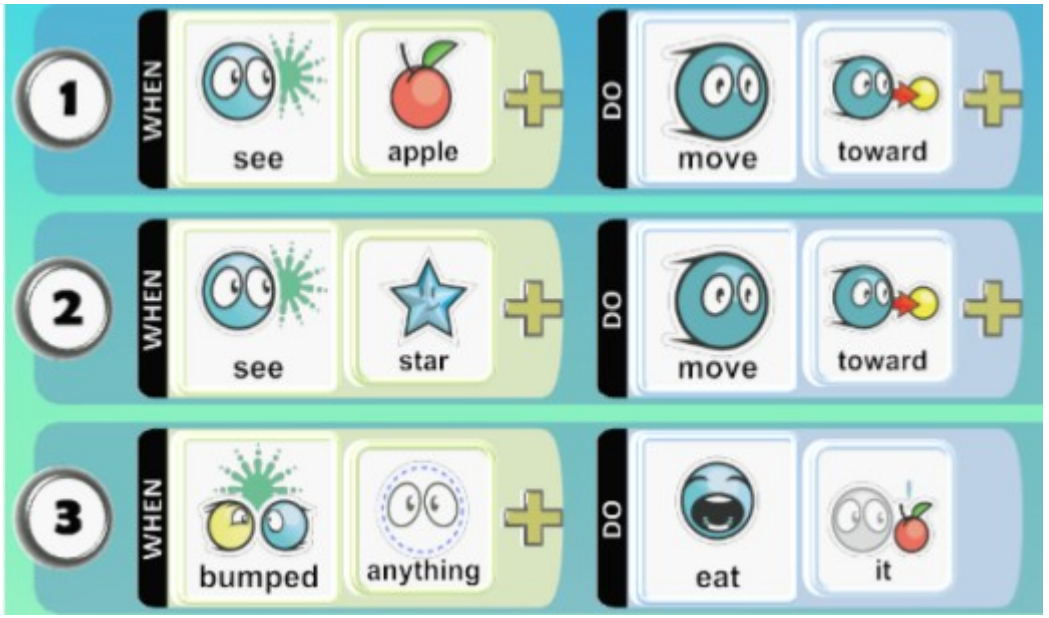
With these three rules, what will the kodu eat first? Circle your answer.

- **a.** Stars
- **b.** Apples
- **c.** Whichever thing is closest, no matter what kind.
- **d.** It will choose randomly.

When will the kodu eat its first star?

- **a.** When there are no apples left.
- **b.** Right after it eats its first apple.
- **c.** It will never eat a star; it will keep looking for apples forever.
- **d.** It will only eat a star if it bumps into one by accident.

Module 1, Question 9



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a. When there are no apples left.
b. Right after it eats its first apple.
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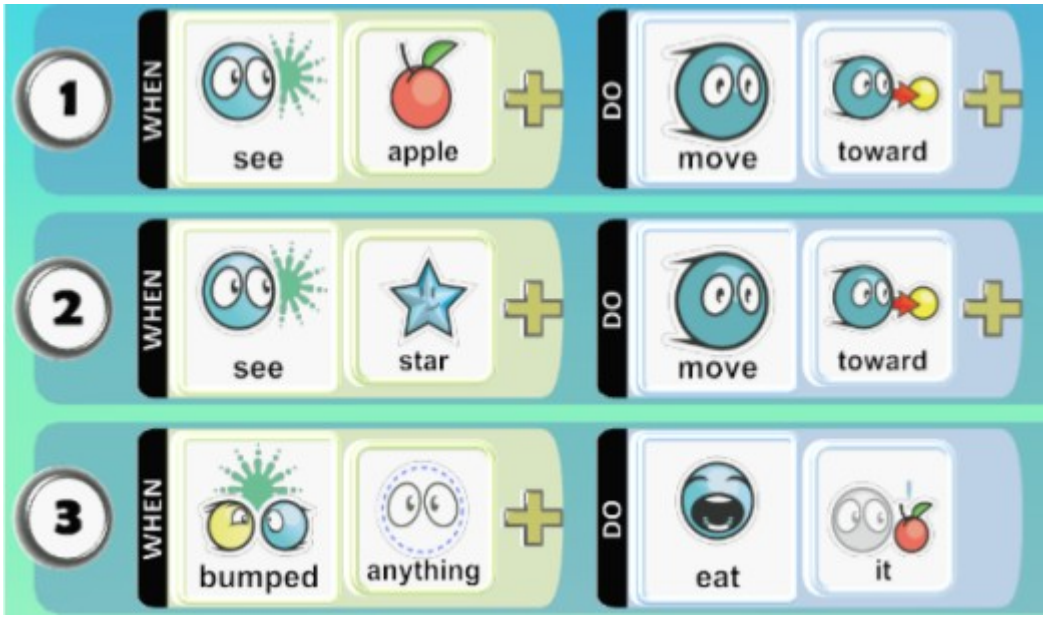
d. It will only eat a star if it bumps into one by accident.

✔ Correct Response
✖ Collective Choice Fallacy

Module 1, Question 9



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b. Apples
c. Whichever thing is closest, no matter what kind.
d. It will choose randomly.

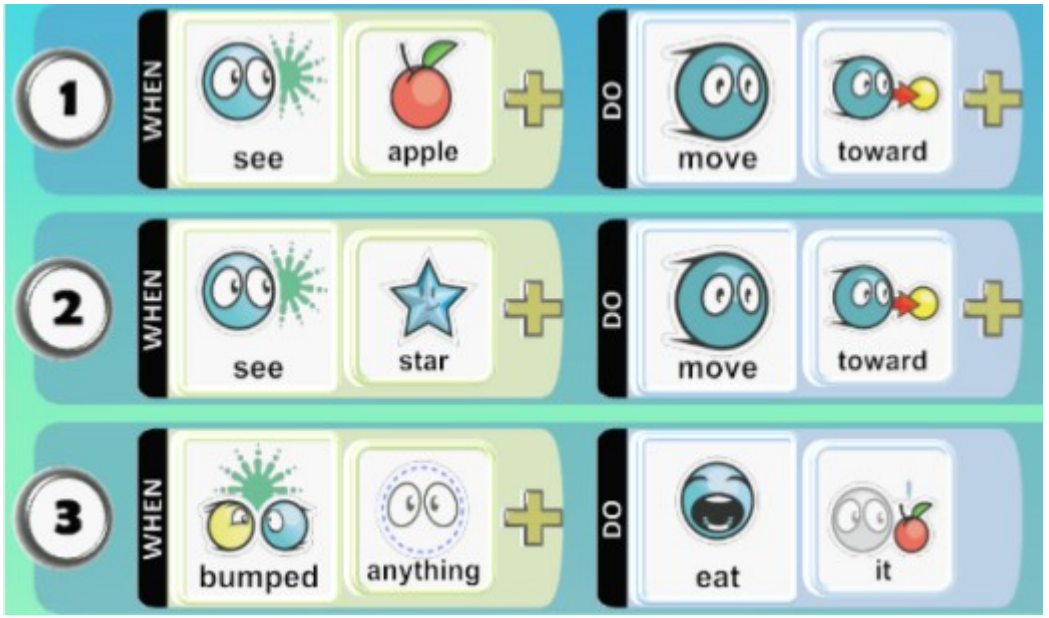
When will the kodu eat its first star?

a. When there are no apples left.
b. Right after it eats its first apple.
c. It will never eat a star; it will keep looking for apples forever.
d. It will only eat a star if it bumps into one by accident.

Harder problem

✔ Correct Response
✖ Collective Choice Fallacy

Module 1, Question 9



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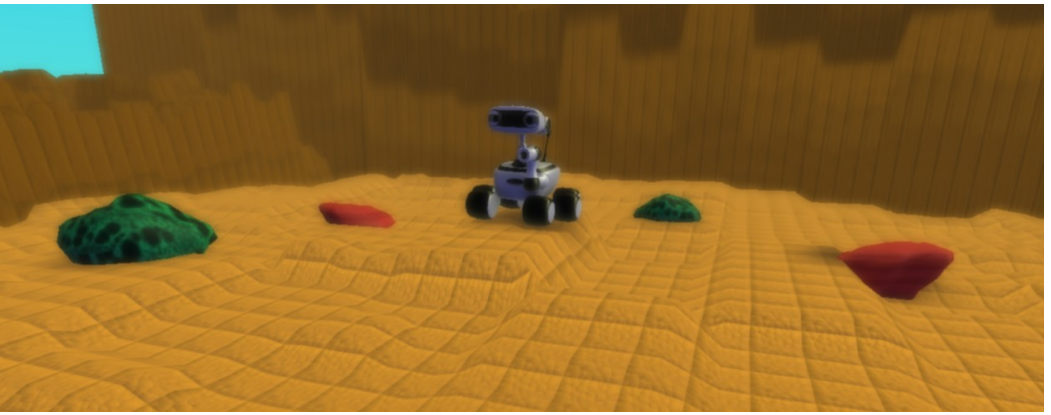
b. Apples
c. Whichever thing is closest, no matter what kind.
d. It will choose randomly.

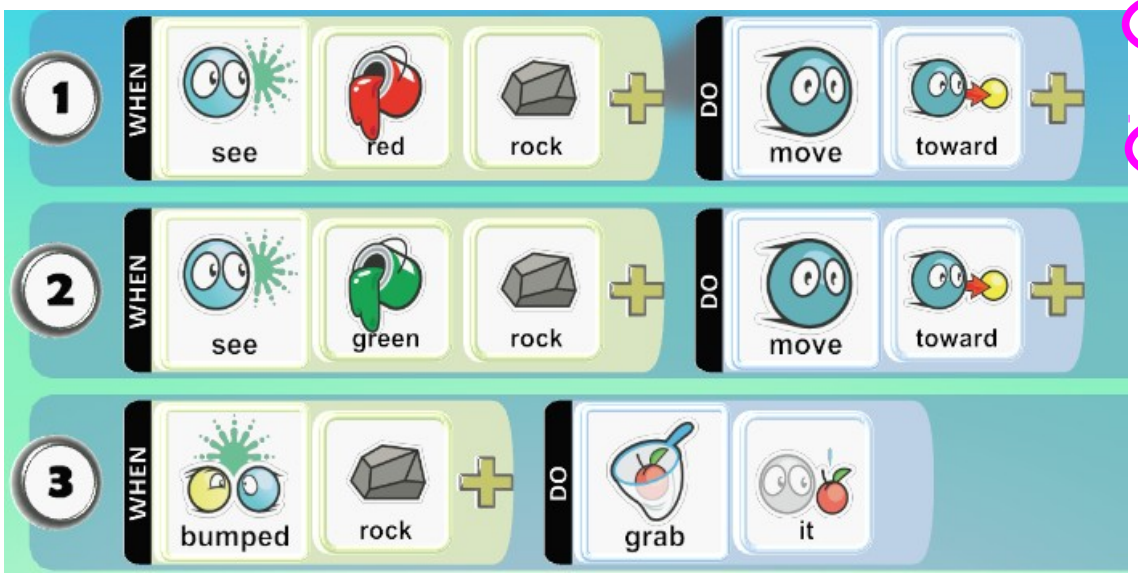
When will the kodu eat its first star?

a. When there are no apples left.
b. Right after it eats its first apple.
c. It will never eat a star; it will keep looking for apples forever.
d. It will only eat a star if it bumps into one by accident.

✔ Correct Response
✖ Seq. Procedure Fallacy
✖ Collective Choice Fallacy
✖ Mis-apply 3rd Law

Module 2, Question 11





With these three rules, what will the rover grab first? Circle your answer.

a. A red rock
b. A green rock
c. It will grab any rock at random.
d. The closest rock no matter what color.

When will the rover grab its first green rock?

a. When the red rocks are gone.
b. Right after it grabs a red rock.
c. It will never grab a green rock; it will keep looking for red rocks.
d. It will only grab a green rock if it bumps into one by accident.

✔ Correct Response
✖ Seq. Procedure Fallacy
✖ Collective Choice Fallacy
✖ Mis-apply 3rd Law

Conflict Resolution Results: Part 1

Problem	Group	A	B	C	D	Total
M1Q9 part 1	Camp 1	1	**14**	5	0	20
	Camp 2	1	**12**	2	3	18
M2Q11 part 1	Camp 1	**17**	0	2	1	20
	Camp 2	**7**	0	0	12	19

✔ Correct Response ✖ Collective Choice Fallacy

Camp 2 (51% correct) underperformed Camp 1 (78% correct).

Conflict Resolution Results: Part 2

Problem	Group	A	B	C	D	Total
M1Q9 part 2	Camp 1	**14**	4	0	0	20*
	Camp 2	**11**	5	0	1	18*
M2Q11 part 2	Camp 1	**18**	1	0	1	20
	Camp 2	**7**	5	2	5	19

✔ Correct Response ✖ Sequential Procedure Fallacy

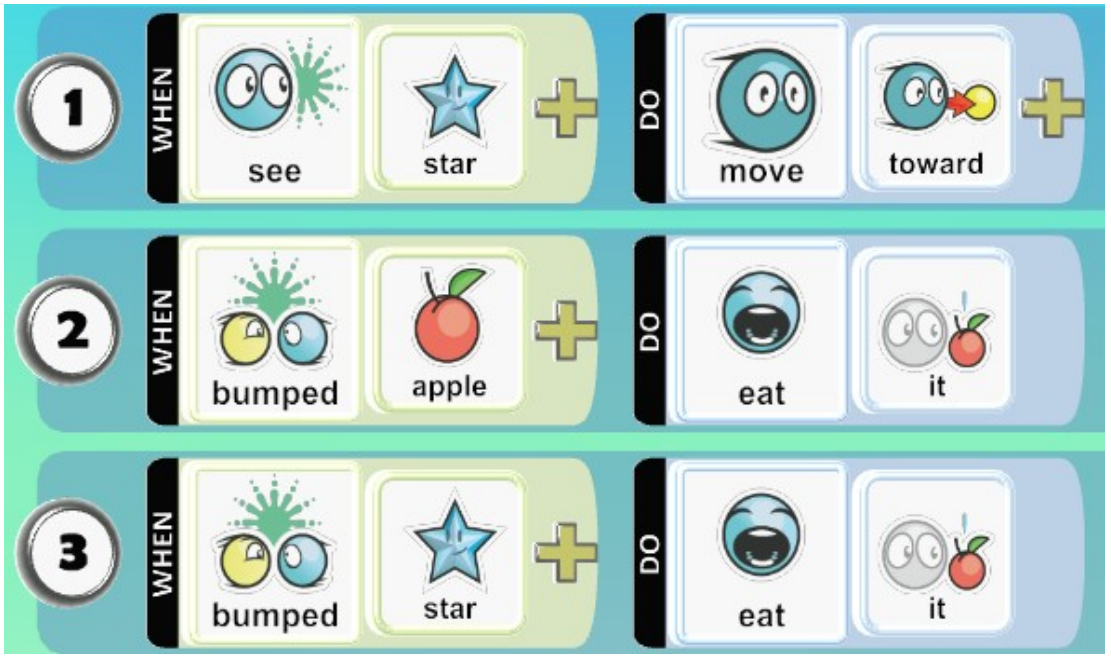
✖ Mis-apply 3rd Law

Camp 2 (47% correct) underperformed Camp 1 (80% correct).

IV. Anomalous Rule Sequences

- Two consume rules but only one pursue rule.
- Students had not encountered this situation in any previous instruction or demonstrations.
- Answering correctly requires careful attention to what the rules say and how the laws govern them.
- Reasoning by analogy to previously seen programs *will not work*.

Module 1, Question 10



With these three rules, what will the kodu eat first?

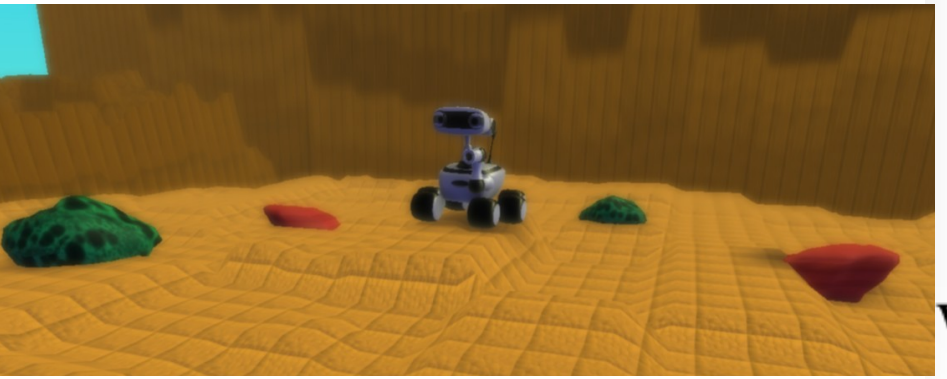
a. Stars
b. Apples
c. Whichever thing is closest.
d. A pizza

When will the kodu eat an apple?

a. When there are no stars left.
b. After it has eaten one star.
c. Never, unless it bumps into an apple by accident.
d. Before it eats its first star.

✔ Correct Response
✖ Seq. Procedure Fallacy
✖ Collective Choice Fallacy
✖ Mis-apply 3rd Law

Module 2, Question 12



With these three rules, what will the rover grab first? Circle your answer.

- **a.** A red rock
- **b.** A green rock
- **c.** It will grab any rock at random.
- **d.** The closest rock no matter what color.

When will the rover grab a red rock?

- **a.** When the green rocks are gone.
- **b.** Right after it grabs a green rock.
- **c.** Before it grabs its first green rock.
- **d.** It will only grab a red rock if it bumps into one by accident.

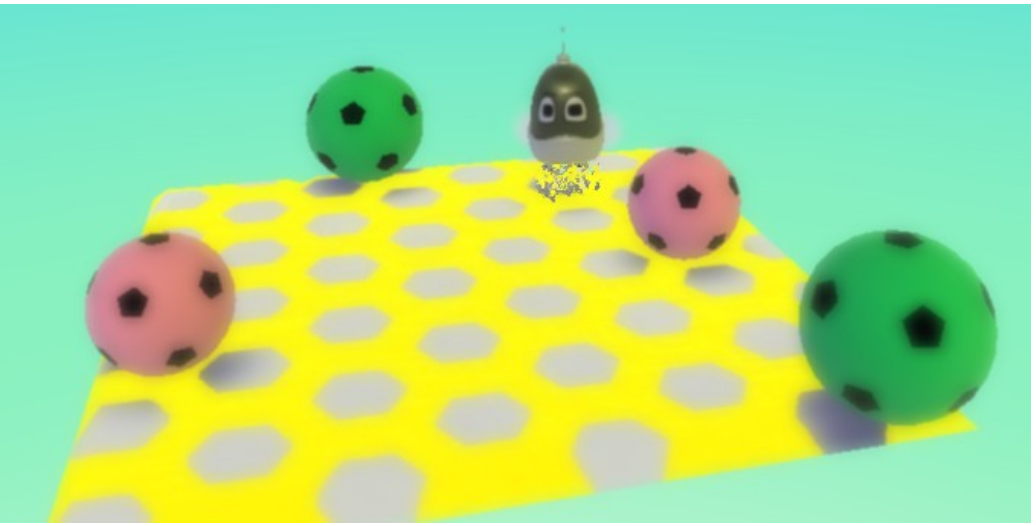
✔ Correct Response

✖ Seq. Procedure Fallacy

✖ Collective Choice Fallacy

✖ Mis-apply 3rd Law

Module 3, Question 6



With these three rules, what will the kodu boom first?

- **a.** A green soccer ball
- **b.** The closest soccer ball of any color
- **c.** A pink soccer ball
- **d.** Nothing

When will the kodu boom a green ball?

- **a.** It will boom green balls first.
- **b.** It will boom green balls when all the pink balls are gone.
- **c.** It will never boom a green ball unless it bumps one by accident.
- **d.** It's random; you can't predict it.

✔ Correct Response

✖ Seq. Procedure Fallacy

✖ Collective Choice Fallacy

✖ Mis-apply 3rd Law

Anomalous Rules Results, part 1

Problem	Group	A	B	C	D	Total
M1Q10 part 1	Camp 1	**19**	1	0	0	20
	Camp 2	**16**	2	0	0	18
M2Q12 part 1	Camp 1	4	**16**	0	0	20
	Camp 2	3	**15**	0	1	19
M3Q6 part 1	Camp 1	8	0	**9**	2	19
	Camp 2	6	1	**11**	1	19

Camps 1 and 2 performed similarly, but percent correct declined over time.

Anomalous Rules Results, part 2

Problem	Group	A	B	C	D	Total
M1Q10 part 2	Camp 1	12	2	**5**	1	20
	Camp 2	6	3	**6**	3	18
M2Q12 part 2	Camp 1	8	2	1	**9**	20
	Camp 2	6	4	1	**8**	19
M3Q6 part 2	Camp 1	6	3	**7**	2	19*
	Camp 2	2	6	**9**	2	19

Camps 1 and 2 performed equally poorly; both got worse over time. Initially they may have only been attending to the first rule, and as they tried harder to reason through the problem, they got confused.

Conclusions

- Kodu's high level primitives afford writing interesting programs that are 2-3 lines long.
- Students could solve some Pursue and Consume problems, but had trouble applying the laws in novel anomalous situations.
  - Need to expose students to more complex cases.
  - Need more explicit instruction on the laws.
- Common reasoning errors:
  - Sequential Procedure Fallacy
  - Collective Choice Fallacy
  - Mis-application of Third Law

Relation to Neo-Piagetian Psychology

Teague and Lister's theory of stages of cognitive development in novice programmers:

- **Sensorimotor:** many misconceptions.
- **Preoperational:** can trace code but can only reason intuitively; don't reliably see relationships between program components.
- **Concrete operational:** can reason more abstractly and recognize higher order relationships.

When they failed to apply the laws correctly, our subjects appeared to be attending to only part of the program (sensorimotor?) or reasoning by analogy to previous programs (intuitive/preoperational?).

More of Our Work at SIGCSE'17

- Poster session 1:45 – 5:00 PM today:

  Ashish Aggarwal:

  Neo-Piagetian Classification of Reasoning Ability and Mental Simulation in Microsoft's Kodu Game Lab.

- Paper on Friday, 11:10 AM

  Ashish Aggarwal, Christina Gardner-McCune, and David S. Touretzky

  Evaluating the Effect of Using Physical Manipulatives to Foster Computational Thinking in Elementary School.