Introduction to Functional Classes in CS1

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Introduction to Functional Classes in CS1

Introduction

- Last year at TFPIE

Design of Classes I

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The use of functional programming languages in the first programming course at many universities is well-established and effective. Invariably, however, students must progress to study object-oriented programming. This article presents how the first steps of this transition have been successfully implemented at Seton Hall University. The developed methodology builds on the students' experience with type-based design acquired in their previous introduction to programming courses. The transition is made smooth by explicitly showing students that the design lessons they have internalized are relevant in object-oriented programming. This allows for new abstractions offered by object-oriented programming languages to be more easily taught and used by students. Empirical evidence collected from students in the course suggests that the approach developed is effective and that the transition is smooth.

1 Introduction

- Designed based introductory courses to programming, inspired by the approach put forth in the textboo

Introduction to Functional Classes in CS1

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- Design-based introduction to programming courses are well-established
- Students are exposed to first-class functions: values

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-

```
;; (X → Y) (Y → Z) → (X → Z)
;; Purpose: Return a function for (f ∘ g)(x)
(define (compose-f-g g f)
  (λ (an-x) (f (g an-x))))

(define add2 (compose-f-g add1 add1))
(define id   (compose-f-g add1 sub1))

(check-expect (add2 3)  5)
(check-expect (id 10)  10)
```

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Introduction

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- Missed opportunity to introduce object-oriented concepts

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- Missed opportunity to introduce object-oriented concepts
- Such an introduction is important
  - Facilitates the transition to object-oriented programming (OOP) and design
  - Appeases other instructors

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Introduction

- The other side of the coin is rarely explored to any depth: data as functions
- Missed opportunity to introduce object-oriented concepts
- Such an introduction is important
  - Facilitates the transition to object-oriented programming (OOP) and design
  - Appeases other instructors
- Main idea: a function implements an interface using message-passing
  - Start with compound data of finite size that does not have variety
  - Move onto implementing union types including compound data of arbitrary size.

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Related Work

- OOP textbooks: emphasize that classes and objects combine code and data

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  - An object is a structure for incorporating data and the procedures for working with that data

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  - An object is a structure for incorporating data and the procedures for working with that data
  - A class is a group of objects that share common state and behavior

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- OOP textbooks: emphasize that classes and objects combine code and data
  - An object is a structure for incorporating data and the procedures for working with that data
  - A class is a group of objects that share common state and behavior
  - Every object is an instance of a class, which serves as the type of the object and as a blueprint, defining the data which the object stores and the methods for accessing and modifying that data

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  - Objects are used to combine data with procedures that operate on that data

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- Show examples to illustrate how to use classes and how to create objects

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  - Objects are used to combine data with procedures that operate on that data
- Show examples to illustrate how to use classes and how to create objects
- The unstated assumption is that beginning students absorb design principles by studying code samples

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- The unpublished textbook `How to Design Classes` is closely coupled with a `DSL` known as `ProfessorJ`

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- An object–an instance of the type defined by the class
- The design of a class starts by understanding how data is to be represented
- Union types are introduced to motivate the need for interfaces
- We use the `Racket` student languages, a specialized `DSL` is not required

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Related Work

- A hybrid approach proposes the use of several `DSLs` embedded in `Racket` before making the full transition into `Java` in a *second semester* course

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- Transition to `Java` occurs in the middle of the semester

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Related Work

- A hybrid approach proposes the use of several `DSLs` embedded in `Racket` before making the full transition into `Java` in a *second semester* course
- Relies heavily of the design recipe to provide a framework for program design and discussion
- Union types and design based on structural recursion are introduced as requiring a distinct class for each subtype
- Transition to `Java` occurs in the middle of the semester
- Our work is not part of an `OOP` course
- Introduce students to object-oriented abstractions within the context of a first programming course using a program by design methodology

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Student Background

- Use `HtDP`
  - Functions
  - Compound data: finite and arbitrary size
  - Functional abstraction: λ and curried functions

Introduction to Functional Classes in CS1

Student Background

```
(define (scale-by-2 L) (map (λ (x) (* 2 x)) L))
(define (scale-by-5 L) (map (λ (x) (* 5 x)) L))
(define (scale-by-3 L) (map (λ (x) (* 3 x)) L))
```

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(define (scale-by-3 L) (map (λ (x) (* 3 x)) L))

;; number → ((listof number) → (listof number))
(define (make-list-scaler sc)
  (λ (L) (map (λ (x) (* sc x)) L)))
```

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(define (scale-by-2 L) (map (λ (x) (* 2 x)) L))
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;; number → ((listof number) → (listof number))
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```

- `make-list-scaler` is
  - a curried function
  - a *class* that returns `objects` that scale a list of numbers by a given scalar

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Student Background

```
(define (scale-by-2 L) (map (λ (x) (* 2 x)) L))
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(define (scale-by-3 L) (map (λ (x) (* 3 x)) L))

;; number → ((listof number) → (listof number))
(define (make-list-scaler sc)
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```

- `make-list-scaler` is
  - a curried function
  - a *class* that returns `objects` that scale a list of numbers by a given scalar
- Connection is not automatically made by students
- Result is twofold:
  - Students gain more interest in the techniques being taught
  - Students obtain an understanding of some `OOP` abstractions

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Structures as Interfaces

- Data definition defines a type
- States nothing about the valid type operations

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Structures as Interfaces

- Data definition defines a type
- States nothing about the valid type operations
- The valid operations are defined in an *interface*

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Structures as Interfaces

```
;; A 3Dposn is a structure:
;;   (make-3Dposn number number number)
(define-struct 3Dposn (x y z))

;; 3Dposn → number
;; Purpose: Return distance to the origin of given 3Dposn
(define (dist-origin a-3dposn)
  (sqrt (+ (sqr (3Dposn-x a-3dposn))
           (sqr (3Dposn-y a-3dposn))
           (sqr (3Dposn-z a-3dposn)))))
```

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           (sqr (3Dposn-z a-3dposn)))))
```

3Dposn interface:

- Request `x`: `number`
- Request `y`: `number`
- Request `z`: `number`
- Request `distance`: `number`

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Structures as Interfaces

- Explicitly relate data and operations

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Structures as Interfaces

- Explicitly relate data and operations
- Related suggests encapsulation
- Functionality provided via *message-passing*
- An interface is implemented by a constructor function
  - called a *class*
  - Returns a message-processing function
  - It's a curried function

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Structures as Interfaces

- Explicitly relate data and operations
- Related suggests encapsulation
- Functionality provided via *message-passing*
- An interface is implemented by a constructor function
  - called a *class*
  - Returns a message-processing function
  - It's a curried function
- An interface must specify the messages used to request a service
- Refine the `3Dposn`:

```
'getx: number
'gety: number
'getz: number
 'd2o: number
```

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Structures and Interfaces

```
(require 2htdp/abstraction)

;; number number number → 3Dposn  Purpose: Return a 3Dposn object
(define (make-3Dposn x y z)
(local [;; 3Dposn → number Purpose: Return distance to origin
        (define (dist-origin x y z) (sqrt (+ (sqr x) (sqr y) (sqr z))))
        ;; message → 3Dposn service throws error  Purpose: Manage messages
        (define (manager m)
          (match m
            ['getx x]
            ['gety y]
            ['getz z]
            ['d2o  (dist-origin x y z)]
            [else (error (string-append "Unknown message to 3Dposn: "
                                        (symbol->string m)))]))]
  manager))
```

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Structures and Interfaces

```
(require 2htdp/abstraction)

;; number number number → 3Dposn  Purpose: Return a 3Dposn object
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(local [;; 3Dposn → number Purpose: Return distance to origin
        (define (dist-origin x y z) (sqrt (+ (sqr x) (sqr y) (sqr z))))
        ;; message → 3Dposn service throws error  Purpose: Manage messages
        (define (manager m)
          (match m
            ['getx x]
            ['gety y]
            ['getz z]
            ['d2o  (dist-origin x y z)]
            [else (error (string-append "Unknown message to 3Dposn: "
                                        (symbol->string m)))]))]
  manager))

(define (3Dposn-x a-3dposn) (a-3dposn 'getx))

(define (3Dposn-y a-3dposn) (a-3dposn 'gety))

(define (3Dposn-z a-3dposn) (a-3dposn 'getz))

(define (dist-origin a-3dposn) (a-3dposn 'd20))
```

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Services that Require More Input

- Add a service that requires more input: Return a function

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Services that Require More Input

- Add a service that requires more input: Return a function

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Services that Require More Input

- Add a service that requires more input: Return a function
- Add distance to

```
'getx: number
'gety: number
'getz: number
 'd2o: number
 'd2p: 3Dposn → number
```

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Services that Require More Input

- Add a service that requires more input: Return a function
- Add distance to

```
'getx: number
'gety: number
'getz: number
 'd2o: number
 'd2p: 3Dposn → number
```

-
```
;; message → 3Dposn service throws error  Purpose: ...
(define (manager m)
  (match m
    ['getx x]
    ['gety y]
    ['getz z]
    ['d2o  (dist-origin x y z)]
    ['d2p  distance]
    [else (error ...)]))
```

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Services that Require More Input

- Add a service that requires more input: Return a function
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```
'getx: number
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```

-
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;; message → 3Dposn service throws error  Purpose: ...
(define (manager m)
  (match m
    ['getx x]
    ['gety y]
    ['getz z]
    ['d2o  (dist-origin x y z)]
    ['d2p  distance]
    [else (error ...)]))
```

-
```
;; 3Dpson → number  Purpose: Compute distance from this to given 3Dposn
(define (distance a-3dposn)
  (sqrt (+ (sqr (- x (3Dposn-x a-3dposn)))
           (sqr (- y (3Dposn-y a-3dposn)))
           (sqr (- z (3Dposn-z a-3dposn))))))
```

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Services that Require More Input

- Add a service that requires more input: Return a function
- Add distance to

```
'getx: number
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-
```
;; message → 3Dposn service throws error  Purpose: ...
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           (sqr (- y (3Dposn-y a-3dposn)))
           (sqr (- z (3Dposn-z a-3dposn))))))
```

-
```
(define (3Dposn-distance p1 p2) ((p1 'd2p) p2))
```

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A Design Recipe for Interfaces

1. Identify the values that must be stored and the services that must be provided.

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A Design Recipe for Interfaces

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2. Develop an interface data definition and a data definition for messages.

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A Design Recipe for Interfaces

1. Identify the values that must be stored and the services that must be provided.
2. Develop an interface data definition and a data definition for messages.
3. Develop a function template for the class that consumes the values that must be stored and whose body is a `local`-expression returning the message-processing function.

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A Design Recipe for Interfaces

1. Identify the values that must be stored and the services that must be provided.
2. Develop an interface data definition and a data definition for messages.
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4. Specialize the signature, purpose, class header, and message-processing function.

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A Design Recipe for Interfaces

1. Identify the values that must be stored and the services that must be provided.
2. Develop an interface data definition and a data definition for messages.
3. Develop a function template for the class that consumes the values that must be stored and whose body is a `local`-expression returning the message-processing function.
4. Specialize the signature, purpose, class header, and message-processing function.
5. Write and make local the auxiliary functions needed by the message-passing function.

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A Design Recipe for Interfaces

1. Identify the values that must be stored and the services that must be provided.
2. Develop an interface data definition and a data definition for messages.
3. Develop a function template for the class that consumes the values that must be stored and whose body is a `local`-expression returning the message-processing function.
4. Specialize the signature, purpose, class header, and message-processing function.
5. Write and make local the auxiliary functions needed by the message-passing function.
6. Write and test a wrapper function for each service.

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Implementing Union Types

```
;; A square is a structure
;;     (make-sq number symbol symbol)
;; with a length, a mode, and a color.
(define-struct sq (length mode color))

;; A rectangle is a structure
;;     (make-rect number number symbol symbol)
;; with a width, length, a mode, and a color.
(define-struct rect (width length mode color))

;; A circle is a structure
;;     (make-circ number symbol symbol)
;; with a length, a mode, and a color.
(define-struct circ (radius mode color))

;; A geometric shape, gs, is either:
;;  1. sq
;;  2. rect
;;  3. circ
```

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Implementing Union Types

- Designing interfaces for a union type requires individually reasoning about each subtype
- Not a huge intellectual leap for students

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Step 1: Values and Services

- Three classes are needed: one for each subtype
  - The `sq` class needs to store a number and two symbols
  - The `rect` class needs to stores two numbers and two symbols
  - The `circ` class needs to store a number and two symbols

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Step 1: Values and Services

- Three classes are needed: one for each subtype
  - The `sq` class needs to store a number and two symbols
  - The `rect` class needs to stores two numbers and two symbols
  - The `circ` class needs to store a number and two symbols
- The new step is defining the behavior for a union type
  - Determine if the gs ia a sq
  - Determine if the gs ia a rect
  - Determine if the gs ia a circ
  - Compute the gs's area
  - Determine if the area of this gs is larger than a given gs

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Step 2: Interface and Message Definitions

```
;; A gs is an interface offering:
;;     'is-sq?:  Boolean
;;   'is-rect?:  Boolean
;;   'is-circ?:  Boolean
;;       'area:  number
;;    'bigger?:  gs → Boolean
```

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Step 3: Class Function Template

```
;; ... → gs
;; Purpose: Return a gs object
(define (class-for-gs ...)
  (local
      :
    [ :
     ;; gs → Boolean
     ;; Purpose: Determine if this' area is larger than the given gs' area
     (define (is-this-bigger? a-gs) ...)

     ;; message → service throws error
     ;; Purpose: Provide service for the given message
     (define (manager m)
       (match m
         ['is-sq? ...]
         ['is-rect?  ...]
         ['is-circ?   ...]
         ['area   ...]
         ['bigger?    ...]
         [else (error (format "Unknown gs service requested: ~s" m))]))]
 manager))
```

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Steps 4 and 5: Class Function Template Specialization

```
(require 2htdp/abstraction)
;; number symbol symbol → gs
;; Purpose: Return a sq object
(define (sq length mode color)
  (local                                  Do the same for every subtype
    [;; gs → Boolean
     ;; Purpose: Determine if this' area > given gs' area
     (define (is-this-bigger? a-gs) (> (sqr length) (gs-area a-gs)))

     ;; message → service throws error
     ;; Purpose: Provide service for the given message
     (define (manager m)
       (match m
         ['get-length length]
         ['get-mode   mode]
         ['get-color  color]
         ['is-sq?     #true]
         ['is-rect?   #false]
         ['is-circ?   #false]
         ['area       (sqr length)]
         ['bigger?    is-this-bigger?]
         [else
          (error (format "Unknown gs service requested: ~s" m))]))]
    manager))
```

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Step 6: Wrapper Functions and Tests

```
(define SQR1  (sq   5 'outline 'green))
(define RECT1 (rect 2 3 'solid 'blue))
(define CIRC1 (circ 7 'outline 'red))

;; gs → Boolean  Purpose: Determine if given gs is a sq
(define (gs-sq? a-gs) (a-gs 'is-sq?))

;; gs → Boolean  Purpose: Determine if given gs is a rect
(define (gs-rect? a-gs) (a-gs 'is-rect?))

;; gs → Boolean  Purpose: Determine if given gs is a circ
(define (gs-circ? a-gs) (a-gs 'is-circ?))

;; gs → Boolean  Purpose: Compute area of given gs
(define (gs-area a-gs) (a-gs 'area))

;; gs gs → Boolean Purpose: Determine if first given gs > second given gs
(define (gs-bigger? this that) ((this 'bigger?) that))

;; Tests for gs interface
(check-expect (gs-sq? SQR1)    #true)
(check-expect (gs-sq? RECT1)   #false)
(check-expect (gs-sq? CIRC1)   #false)
      :
```

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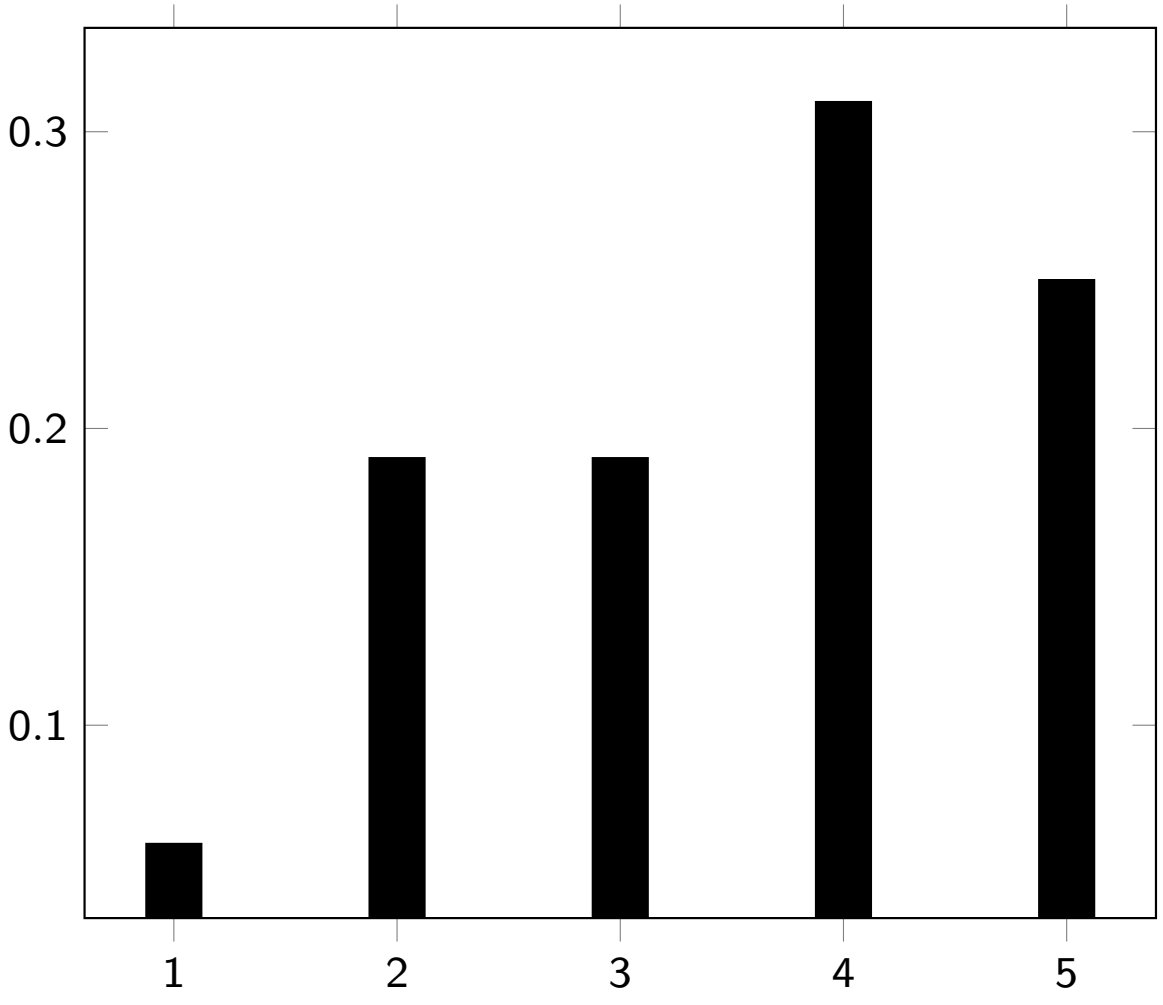
Student Feedback



- How effective How to Design Programs → design classes?

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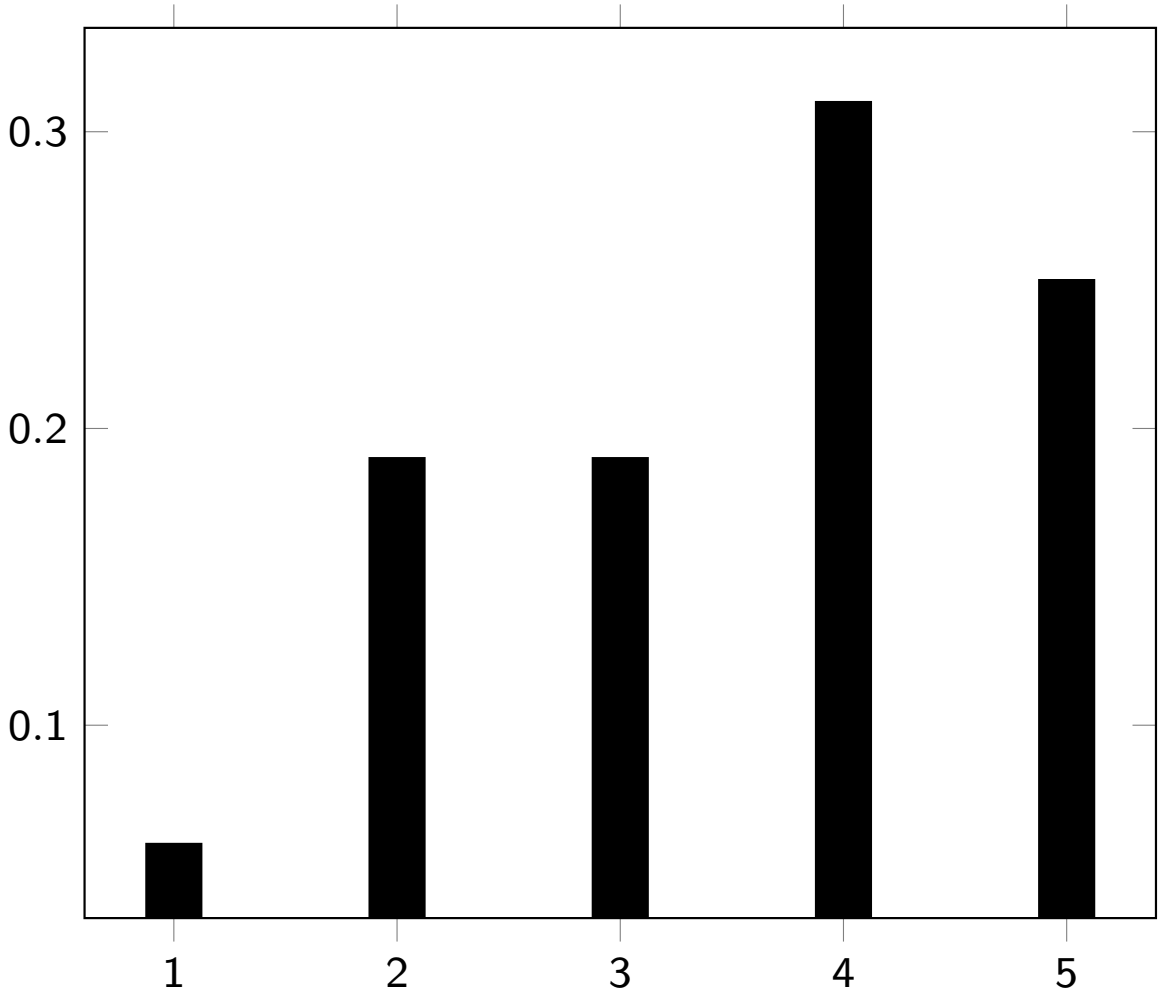

- How effective How to Design Programs → design classes?
- Students expressed appreciation for classes before learning Java
- Students that arrived with prior OOP experience from high school
  - Expressed feeling frustrated with the approach at the beginning
  - Now feel they understand OOP much better

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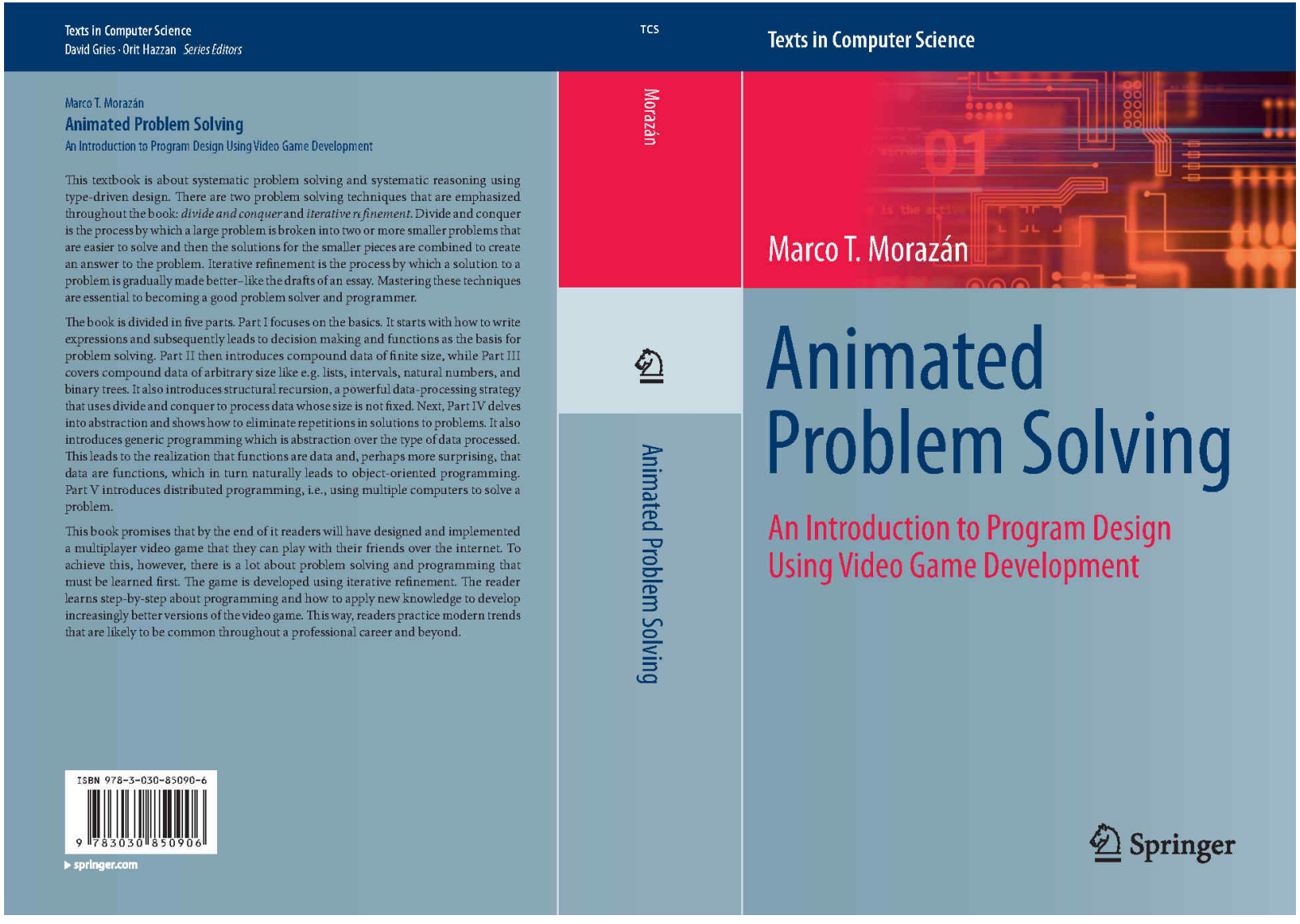
Questions



Questions?