Prototyping
“Systems that Explain Themselves”
for Education

A long lasting interdisciplinary process

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Graz University of Technology,
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ThEdu’17 at CADE 26
6. Aug. 2017

Outline

1. Introduction
   - Existing prototypes/systems
2. Experiments with $\mathcal{ISAC}$'s prototype on . . .
   - covering all phases of problem solving
   - supporting independent learning
   - fostering abstraction by operation
   - connecting application — theory
3. Technical issues with prototyping in $\mathcal{ISAC}$
   - System architecture
   - Efficient programming for authors
   - Formulas in LaTeX quality
   - Funding
4. Conclusions

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Existing prototypes

	based on . . .	
E-Math	PVS	`http://emath.eu/en/`
Mathtoys	TODO	`http://mathtoys.org/`
Edukera	Coq	`https://www.edukera.com/`
$\mathcal{ISAC}$	Isabelle	`http://www.ist.tugraz.at/isac/`
? others	?	?

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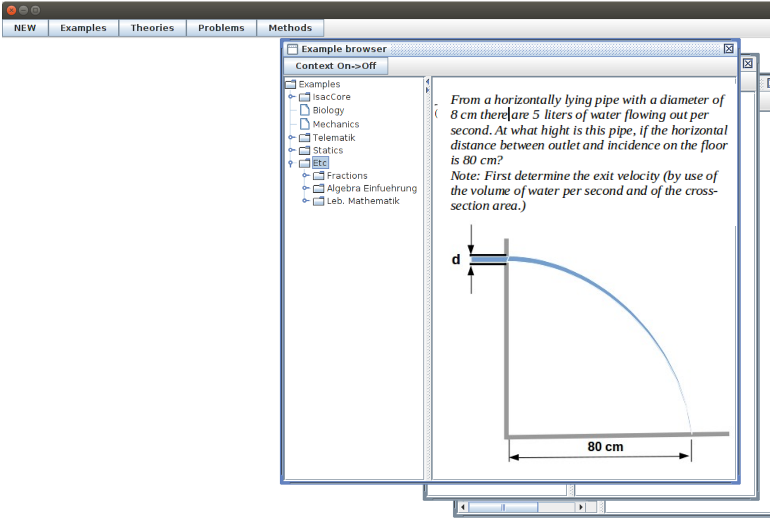
4 Conclusions

Start Example



From a horizontally lying pipe with a diameter of 8 cm there are 5 liters of water flowing out per second. At what hight is this pipe, if the horizontal distance between outlet and incidence on the floor is 80 cm?

Note: First determine the exit velocity (by use of the volume of water per second and of the cross-section area.)

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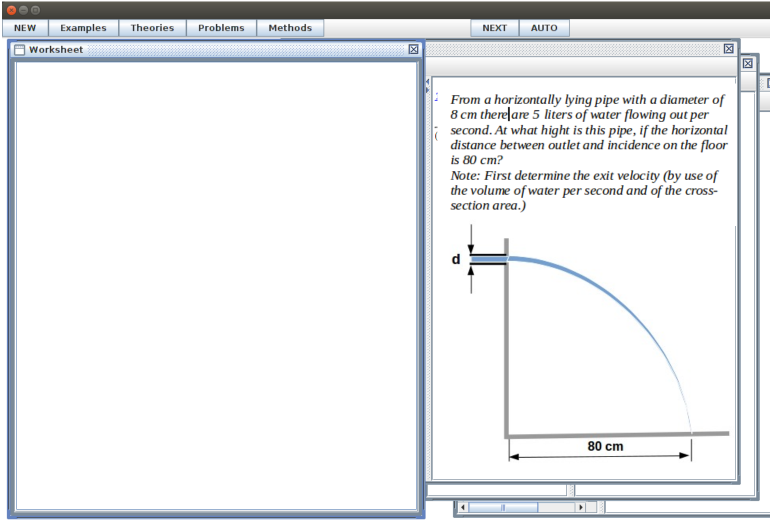

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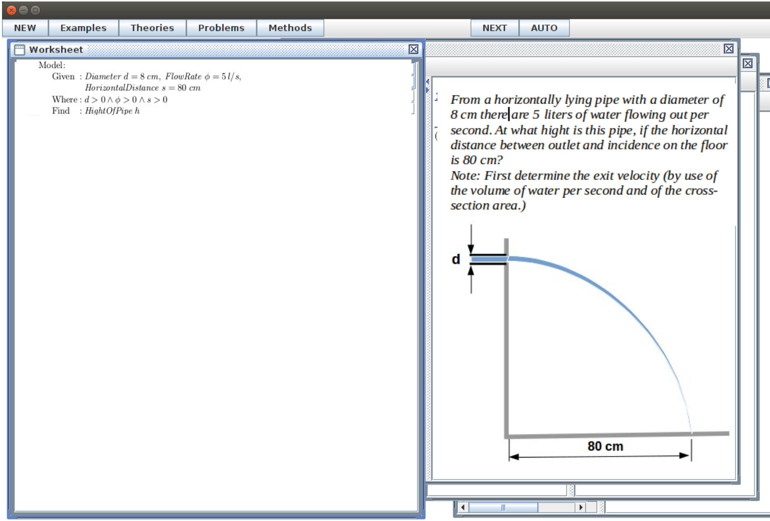
Modelling Phase finished



Model:

Given : $Diameter\ d = 8\ cm,\ FlowRate\ \phi = 5\,l/s,$
$HorizontalDistance\ s = 80\ cm$

Where : $d > 0 \wedge \phi > 0 \wedge s > 0$

Find : $HightOfPipe\ h$

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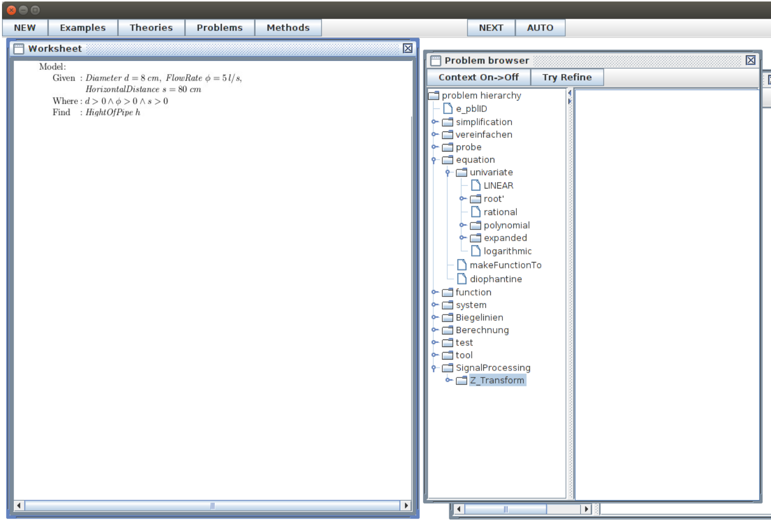

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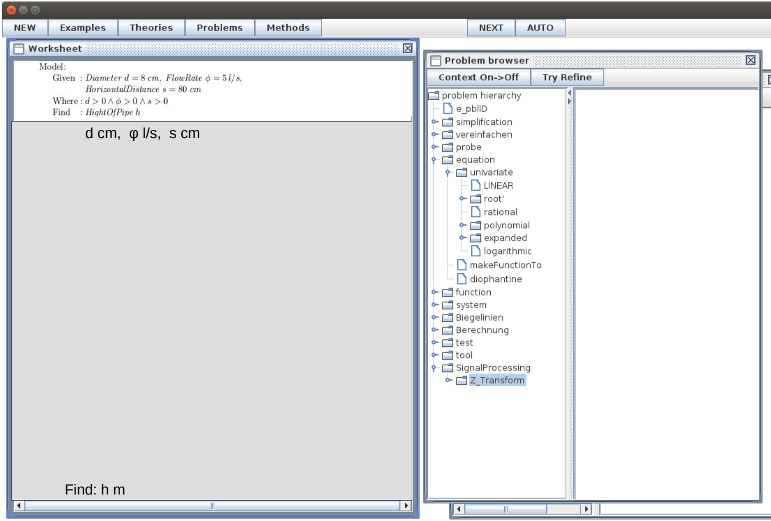

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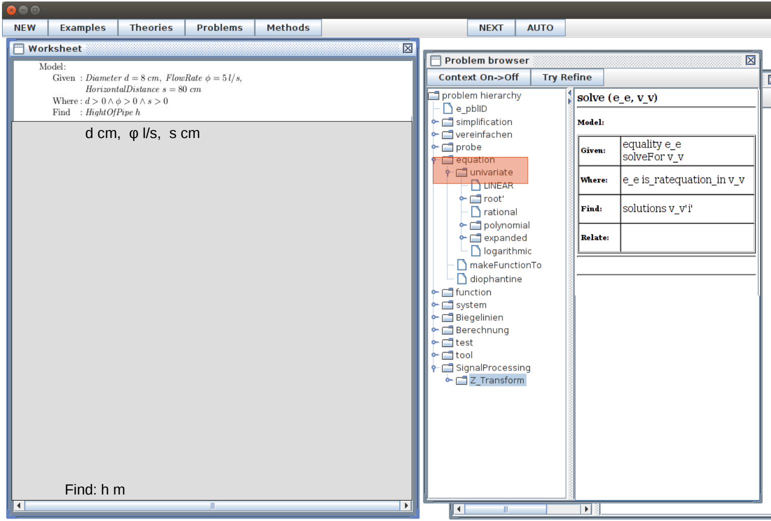
d cm, φ l/s, s cm

Find: h m

Aspect 1: knowledge not impl.



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solve (e_e, v_v)

Model:

Given:	equality e_e solveFor v_v
Where:	e_e is_ratequation_in v_v
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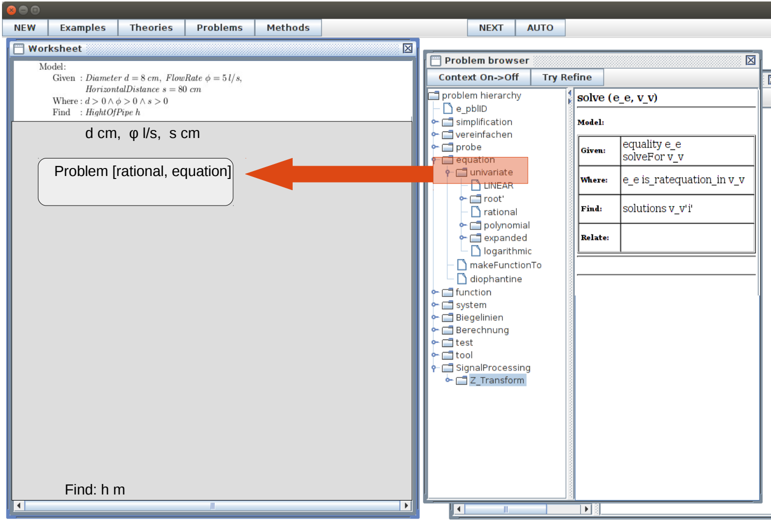
Aspect 2: select knowledge



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Problem [rational, equation]

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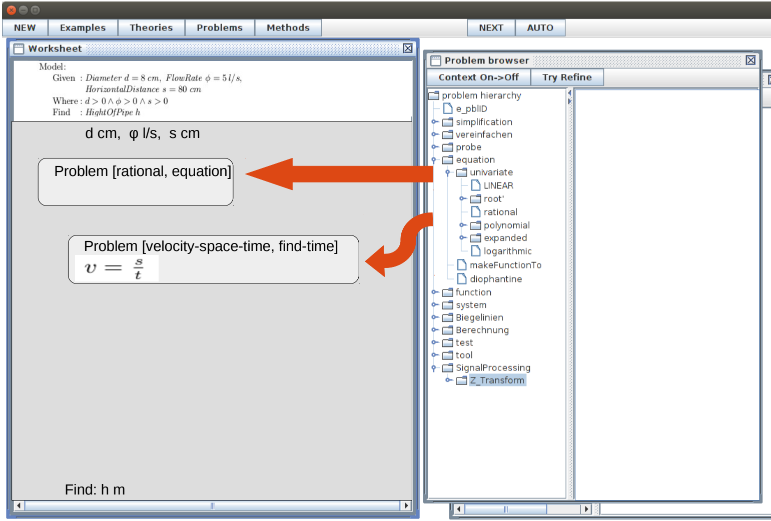

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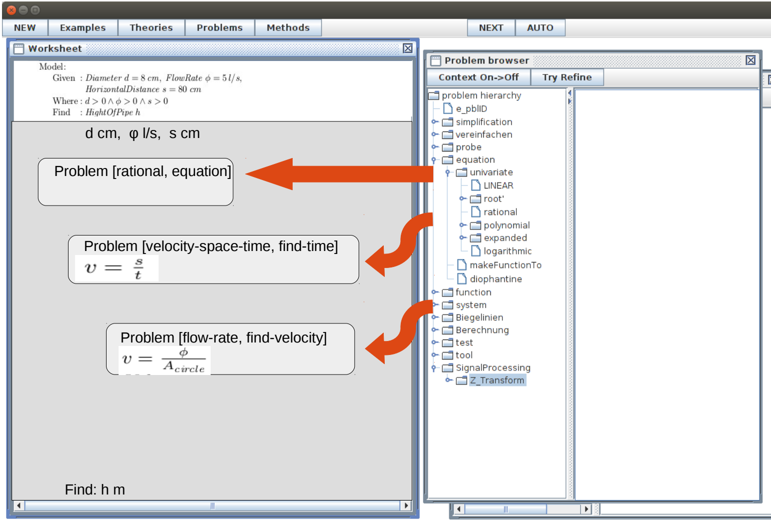

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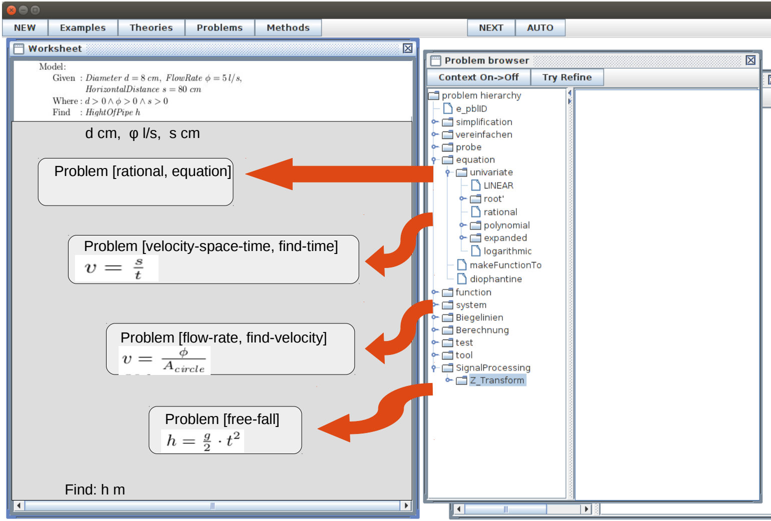

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Problem [free-fall]
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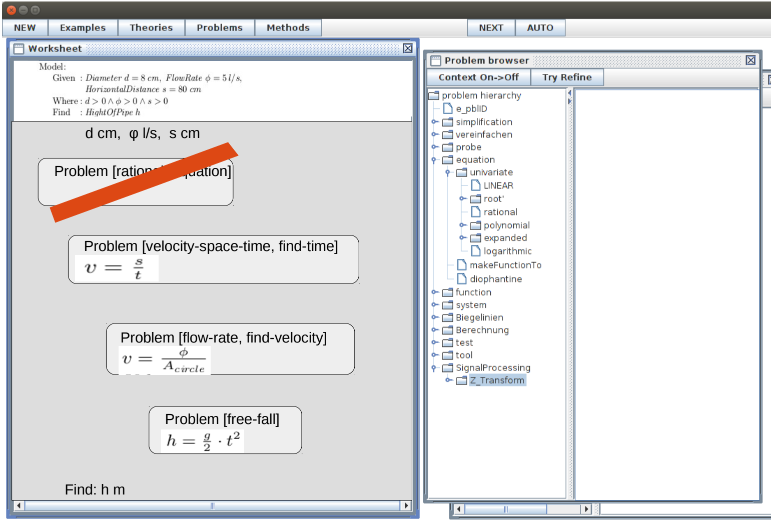
Aspect 2: del. irrelevant knowl.



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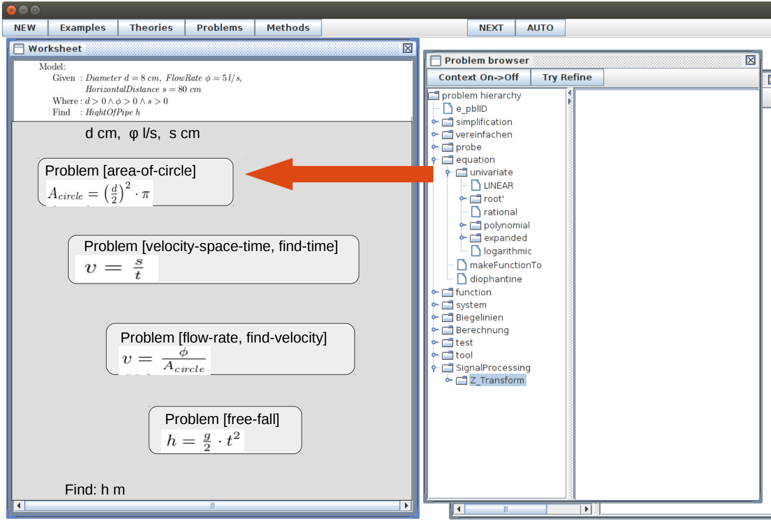

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$A_{circle} = \left(\frac{d}{2}\right)^2 \cdot \pi$

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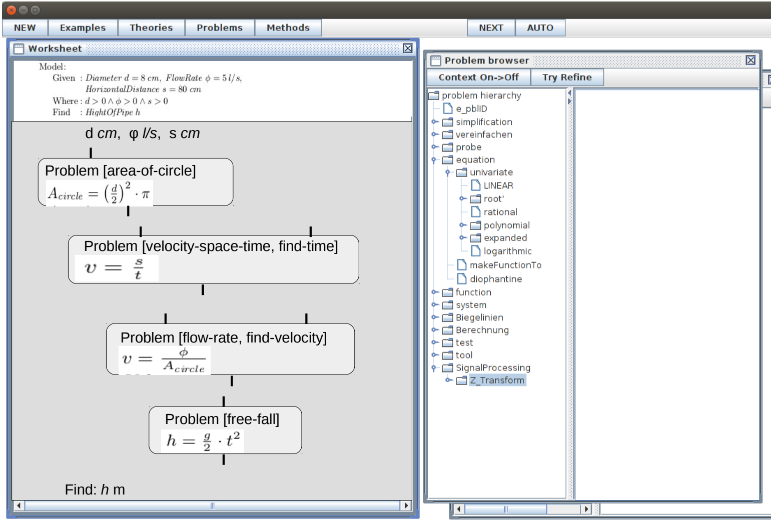
Aspect 3: is given, to be found?



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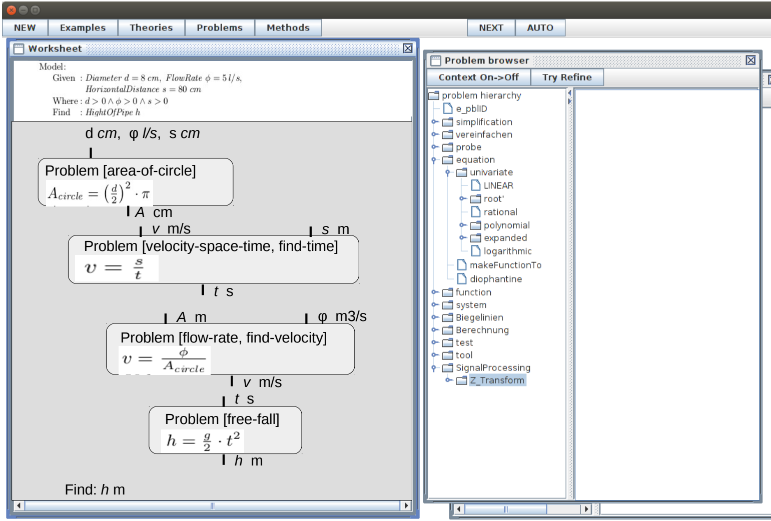

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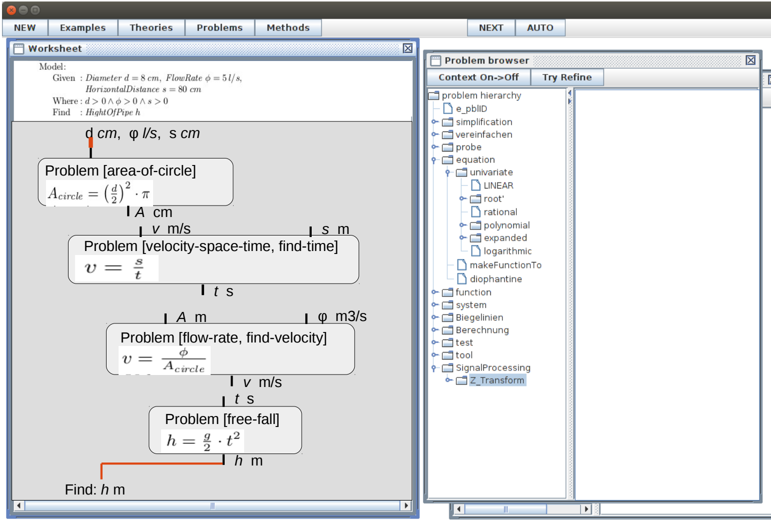

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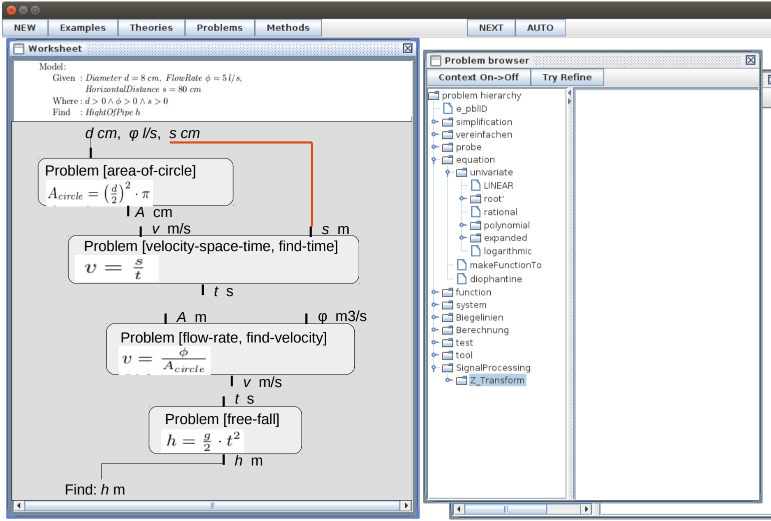

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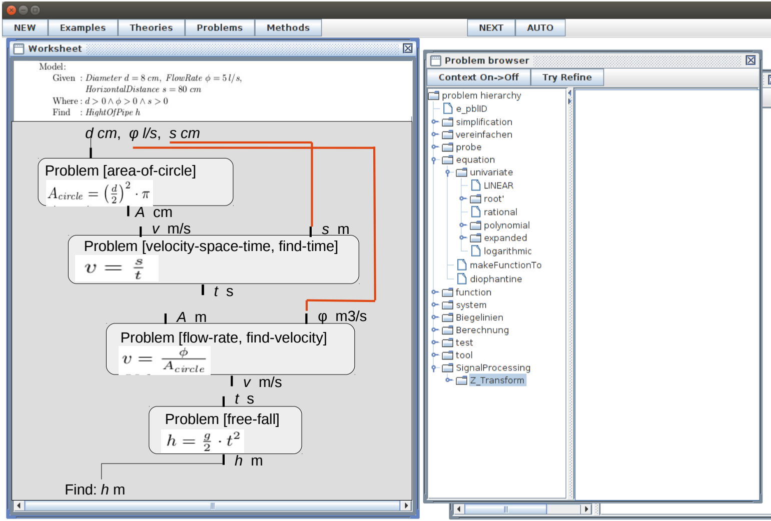

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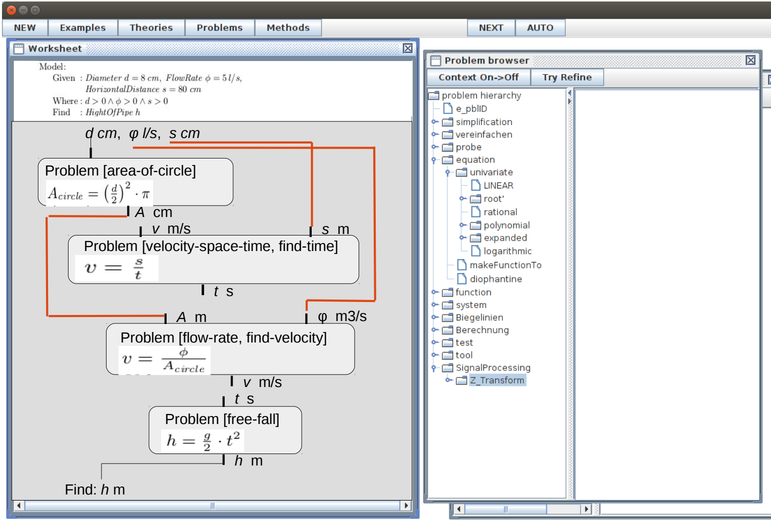

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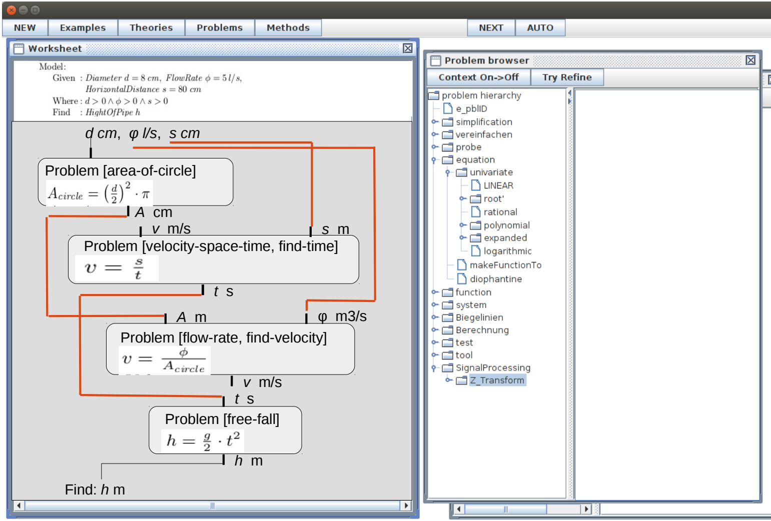

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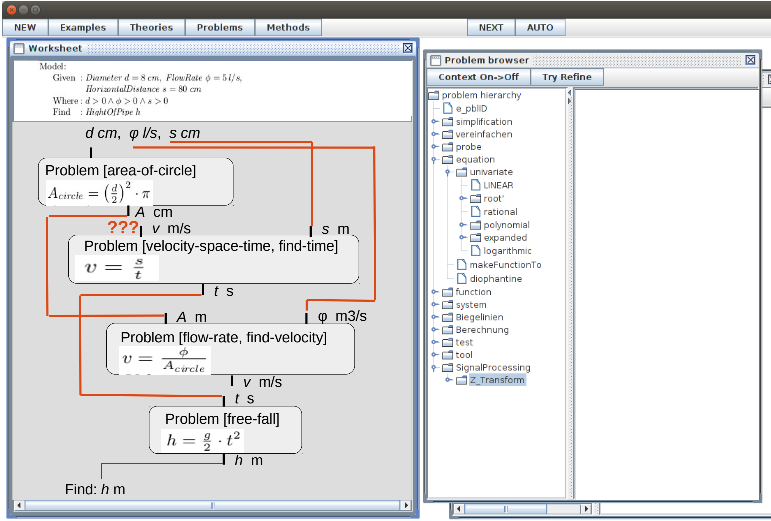
Aspect 3: dangling connect.???



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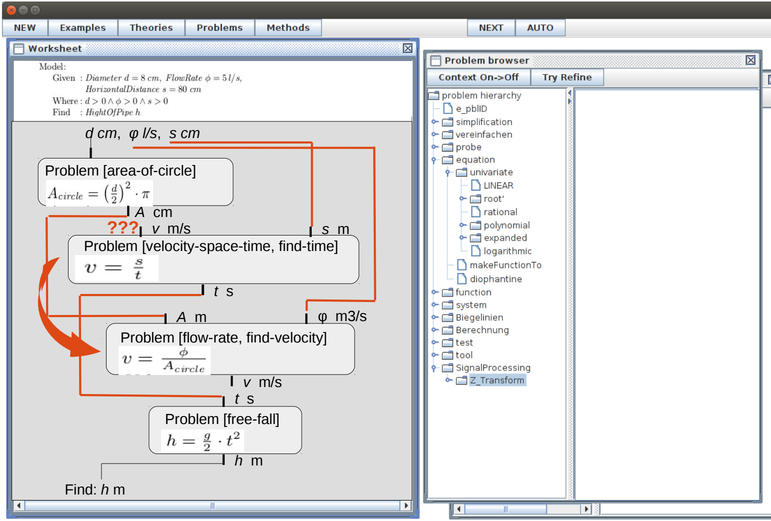
Aspect 3: try another sequence



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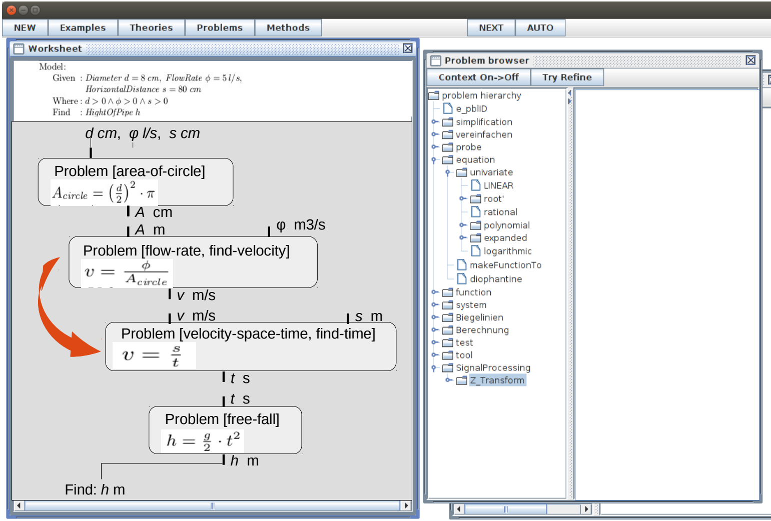
Aspect 3: flip subproblems



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d cm, φ l/s, s cm

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A cm

A m

φ m3/s

Problem [flow-rate, find-velocity]
$$v = \frac{\phi}{A_{circle}}$$

v m/s

v m/s

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Problem [velocity-space-time, find-time]
$$v = \frac{s}{t}$$

t s

t s

Problem [free-fall]
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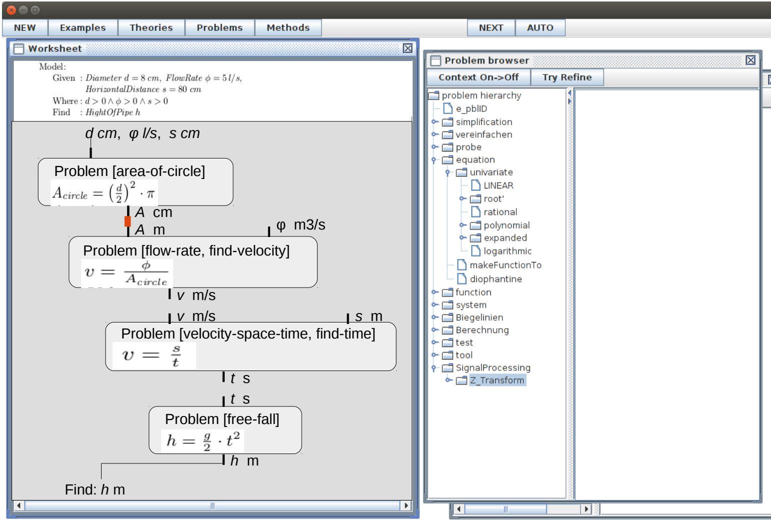
h m

Find: h m

Aspect 3: connect “given”–“find”



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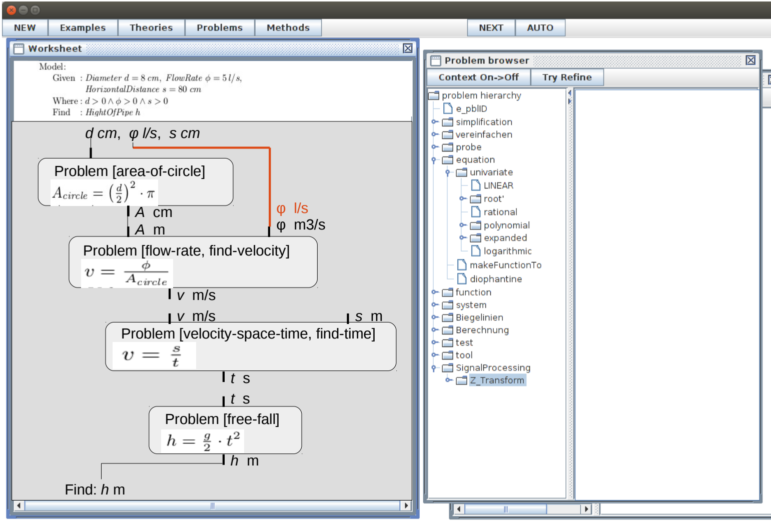

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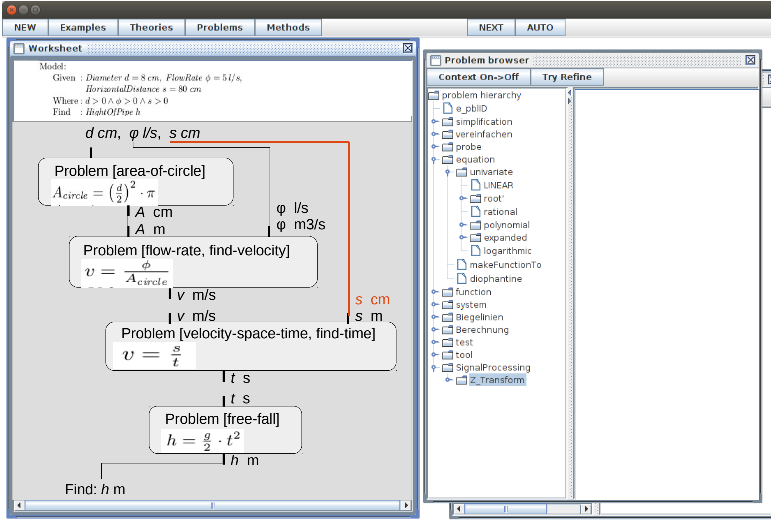

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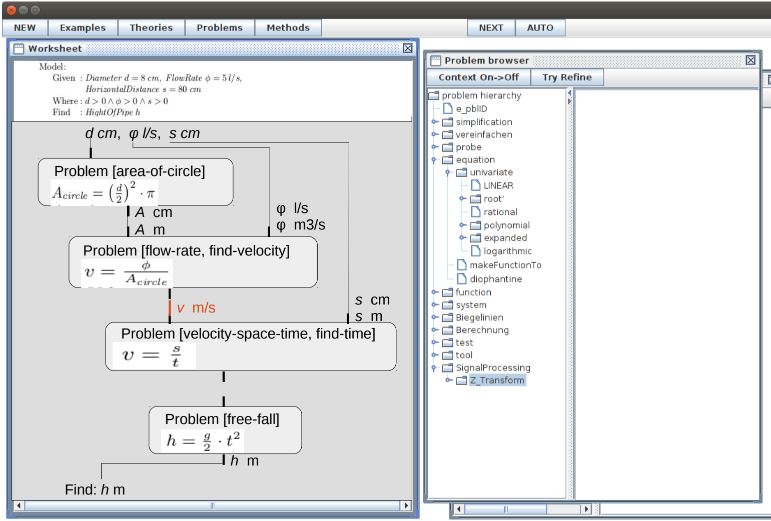

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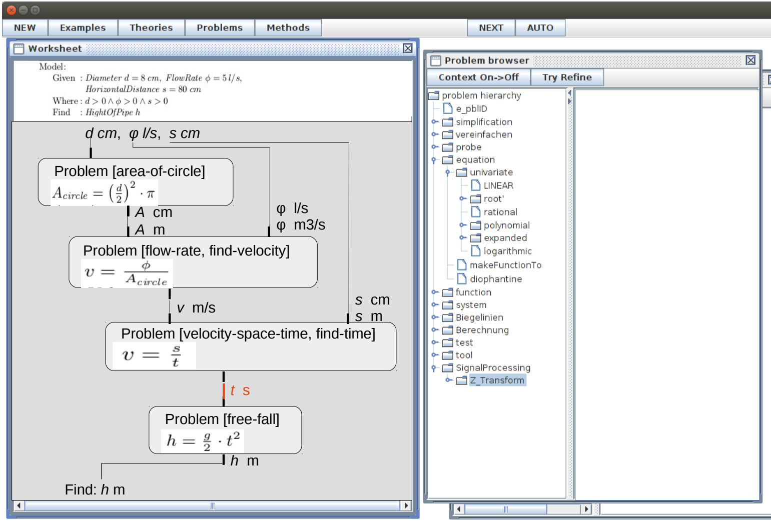

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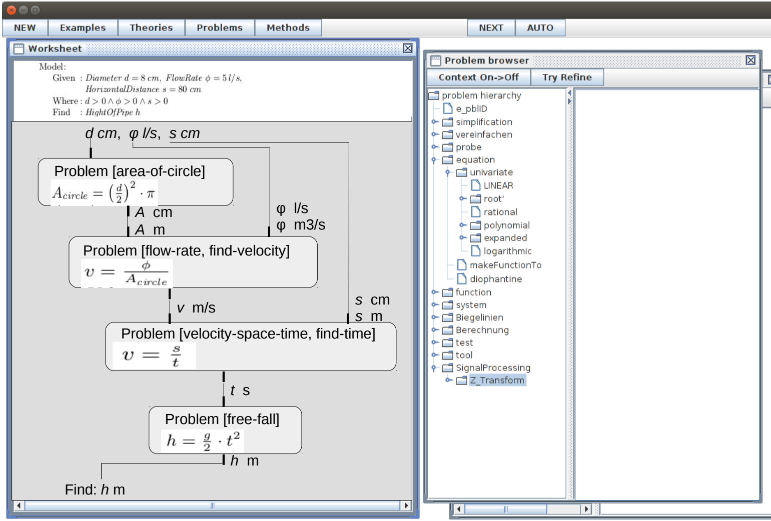
Aspect 3: connections complete



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Where : $d > 0 \wedge \phi > 0 \wedge s > 0$
Find : *HightOfPipe* h

d cm, φ l/s, s cm
Problem [area-of-circle]
$A_{circle} = \left(\frac{d}{2}\right)^2 \cdot \pi$
A cm
A m
φ l/s
φ m3/s
Problem [flow-rate, find-velocity]
$v = \frac{\phi}{A_{circle}}$
v m/s
s cm
s m
Problem [velocity-space-time, find-time]
$v = \frac{s}{t}$
t s
Problem [free-fall]
$h = \frac{g}{2} \cdot t^2$
h m
Find: h m

- problem hierarchy
  - e_pblID
  - simplification
  - vereinfachen
  - probe
  - equation
    - univariate
      - LINEAR
      - root'
      - rational
      - polynomial
      - expanded
      - logarithmic
    - makeFunctionTo
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  - function
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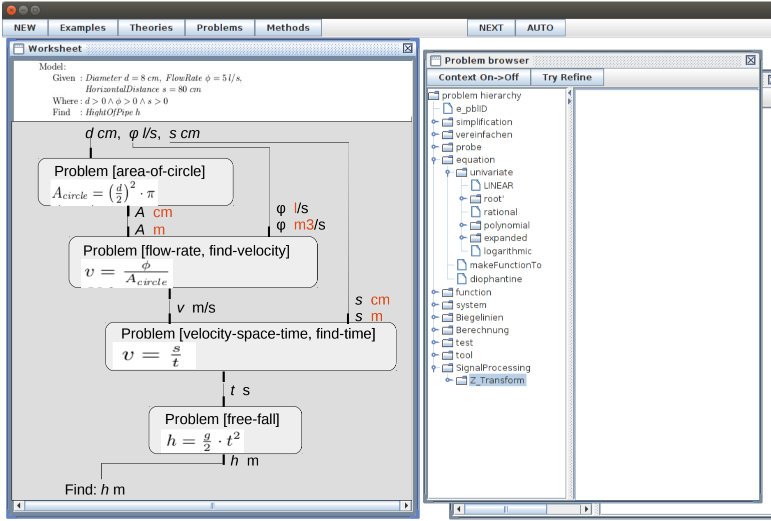
  - Biegelinien
  - Berechnung
  - test
  - tool
  - SignalProcessing
    - Z_Transform

Aspect 4: unit conversions



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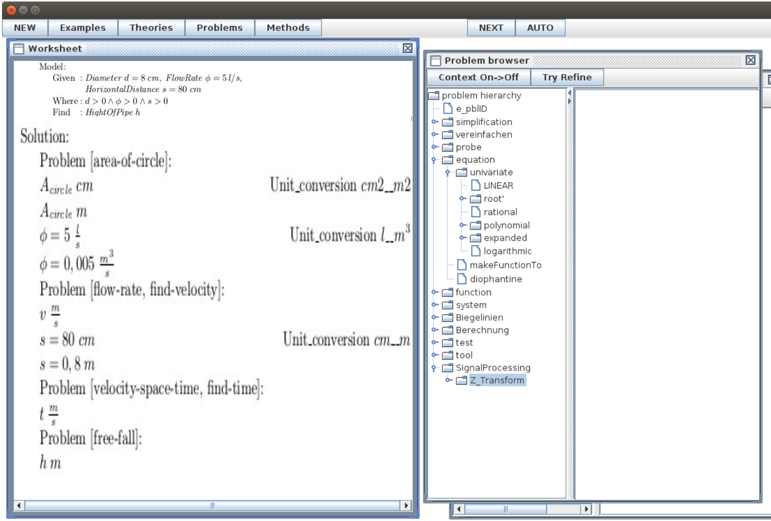
Begin solving phase: units only



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Find : *HightOfPipe* h

Solution:

Problem [area-of-circle]:

$A_{circle}\ cm$ Unit_conversion $cm2\_m2$

$A_{circle}\ m$

$\phi = 5\ \frac{l}{s}$ Unit_conversion l_m^3

$\phi = 0,005\ \frac{m^3}{s}$

Problem [flow-rate, find-velocity]:

$v\ \frac{m}{s}$

$s = 80\ cm$ Unit_conversion cm_m

$s = 0,8\ m$

Problem [velocity-space-time, find-time]:

$t\ \frac{m}{s}$

Problem [free-fall]:

$h\ m$

```
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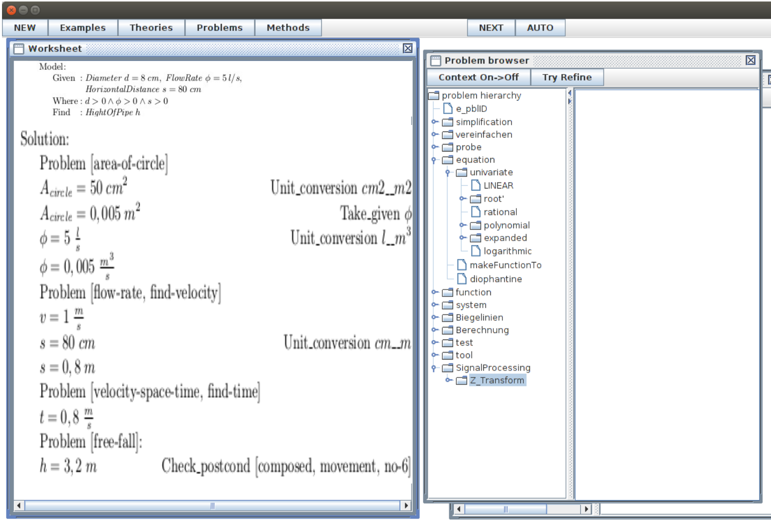
End solving phase: complete



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Solution:

Problem [area-of-circle]

$A_{circle} = 50\ cm^2$ Unit_conversion $cm2\_m2$

$A_{circle} = 0,005\ m^2$ Take_given ϕ

$\phi = 5\ \frac{l}{s}$ Unit_conversion l_m^3

$\phi = 0,005\ \frac{m^3}{s}$

Problem [flow-rate, find-velocity]

$v = 1\ \frac{m}{s}$

$s = 80\ cm$ Unit_conversion cm_m

$s = 0,8\ m$

Problem [velocity-space-time, find-time]

$t = 0,8\ \frac{m}{s}$

Problem [free-fall]:

$h = 3,2\ m$ Check_postcond [composed, movement, no-6]

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1 Introduction
- Existing prototypes/systems

2 Experiments with $\mathcal{ISAC}$'s prototype on . . .
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- fostering abstraction by operation
- connecting application — theory

3 Technical issues with prototyping in $\mathcal{ISAC}$
- System architecture
- Efficient programming for authors
- Formulas in LaTeX quality
- Funding

4 Conclusions

independent learning

demonstrate interaction on

$$\frac{d}{d\,x}\;x^2 + \sin(3 * x^4)$$

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abstraction by operation

Walther Neuper.
Formal abstraction in engineering education — challenges and technology support.
Acta Didactica Napocensia, 9(4), 2017.
Preprint at
`http://www.ist.tugraz.at/projects/isac/publ/sys-explain-eng-edu.pdf`.

Outline

application — theory

demonstrate folding / unfolding

engineering problem (“Biegelinie”)

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System architecture

The $\mathcal{ISAC}$ prototype has

$\mathcal{ISAC}$-frontend	⟵	libisabelle	⟶	Isabelle/$\mathcal{ISAC}$
JavaSwing + Scala		Scala + XML		SML
multi-user sessions		terms		

we want

jEdit | TODO | browser	⟵	PIDE	⟶	Isabelle/$\mathcal{ISAC}$
		markup		
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Programming for authors

The $\mathcal{ISAC}$ prototype has

$\mathcal{ISAC}$ prog.language

```
"program Differentiate f v =
let f' = Take (d_d v f)
in (Try Rewrite_Set norm_Rational
   Try (Rewrite_Set_Inst [(bdv, v)] norm_diff)
   Try (Rewrite_Set norm_Rational)) f'"
```

Lucas-Interpreter
dialog authoring

we want

Isabelle's function package + Lucas-Interpreter

```
partial_function Differentiate :: "real⇒real⇒real⇒"
where
"let f' = Take (d_d v f)
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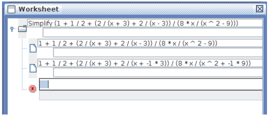
LaTeX formulas

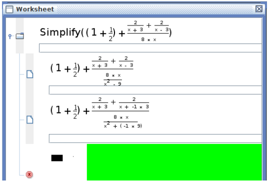
The *ISAC* prototype has



```
Simplify (1 + 1 / 2 + (2 / (x + 3) + 2 / (x - 3)) / (8 * x / (x ^ 2 - 9)))
1 + 1 / 2 + (2 / (x + 3) + 2 / (x - 3)) / (8 * x / (x ^ 2 - 9))
1 + 1 / 2 + (2 / (x + 3) + 2 / (x + -1 * 3)) / (8 * x / (x ^ 2 + -1 * 9))
```

formulas represented as strings generated from Scala `term`

we want



$$\mathrm{Simplify}\left(\left(1+\frac{1}{2}\right)+\frac{\frac{2}{x+3}+\frac{2}{x-3}}{8*x}\right)$$

$$\left(1+\frac{1}{2}\right)+\frac{\frac{2}{x+3}+\frac{2}{x-3}}{\frac{8*x}{x^2-9}}$$

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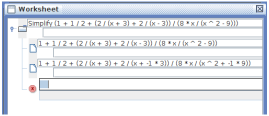
LaTeX formulas

The $\mathcal{ISAC}$ prototype has



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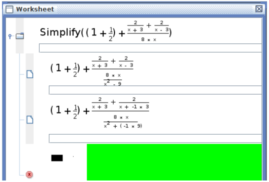

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- *not* as fundamental research (Austrian FWF)
- *not* by EU framework Horizon 2020:
  proposal 2011 rejected, framework didn't change
- hopefully as "applied R&D" (Austrian FFG)
  - developed at Austrian universities
  - applied by Austrian universities
  - applied by Austrian firms (a specific topic):
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  - ? content merchandised by a commercial publisher,
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  - system interfaces stabilised
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  - interdisciplinary contacts established
  - students' contributions were inspiring and cheap
- now $\mathcal{ISAC}$'s code-base is too complex for students' work
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