A Scoping Review of Computational Thinking in K-12 Mathematics Education

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My Research Interests

- Computer Science Education
- Supporting K-12 teachers learn Coding and Computational Thinking
- Particularly in Stage 3 (Years 5 & 6)
- Providing learning environments in which students (and teachers) can *tinker*, *create*, *collaborate* and *share*

Presentation Contents

- Explanation of Key Terms
- Background & Context
- Computational Thinking and Maths
- Aims & Research Questions
- Methodology
- Results
- Conclusions

Key Terms

What is a Scoping Review?

- A type of Literature Review
- Different to a Systematic Review[1]
  - Less specific research questions
  - Broader view, more types of study designs
- Should be transparent and replicable

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[1] Arksey, H. and O'Malley, L. (2005) Scoping studies: towards a methodological framework, International Journal of Social Research Methodology, 8, 1, 19-32.

What is Computational Thinking?

- Wing[2] defined this as: "Thinking like a Computer Scientist"
- An approach to solving problems such that they can be solved by a computer
- Essential for the design of algorithms (step-by-step and precise instructions)
- Wing argued that CT was a skill that could be used by everyone - not just Computer Scientists

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[2] Wing, J. M. (2006). Computational thinking. Communications of the ACM, 49(3), 33-35.

What is Computer Science?

What would we like our children… …to learn about computer science in schools? We need to do away with the myth that computer science is about computers. ***Computer science is no more about computers than astronomy is about telescopes****, biology is about microscopes or chemistry is about beakers and test tubes.* ***Science is not about tools, it is about how we use them and what we find out when we do.***[3]

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[3] Fellows, M., & Parberry, I. (1993). SIGACT trying to get children excited about CS. Computing Research News, 7.

Coding/Programming vs CT

- You may have heard of the Hour of Code[4] or similar initiatives
- Coding and Programming usually mean the same thing
- Coding is the act of writing instructions that a computer can understand
- CT is *probably* best learned through Coding, but there are *unplugged* methods for teaching it as well

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[4] https://code.org/learn

Background / Context

CT in Global Curricula

- Australia: the national Digital Technologies curriculum
  - From K-8 compulsory, elective 9-10
  - CT and Programming are central to this subject[5]
- England: Computing Curriculum
- United States: Computer Science For All

[5] http://www.australiancurriculum.edu.au/technologies/digital-technologies/curriculum/f-10?layout=1

Why Teach CT & Programming?

Guzdial[6] gave four reasons for teaching programming:

- Jobs
- Learning about the "Digital World"
- Computational Literacy
- Broadening Participation

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[6] Guzdial, M. (2015). Learner-Centered Design of Computing Education: Research on Computing for Everyone. Synthesis Lectures on Human-Centered Informatics, 8(6), 1-165.

My Own Views

- I am sceptical about claims that learning CT and programming makes you smarter & a better problem solver
- Also sceptical that students will learn CT on their own (with little guidance)
- I do think that all students should be given the opportunity to create and share programs that are meaningful to them
- I also think there are many opportunities for using CT to enhance lessons in other subjects (e.g. maths)

Computational Thinking & Maths

Seymour Papert & "Mathland"

- Papert, a mathematician and protégé of Piaget
- Co-creator of LOGO, a programming language, in 1967
- Discussed the idea of "Mathland" - an environment in which students could learn maths in an authentic way
- Envisioned the use of LOGO for exploration of "powerful ideas"[9]

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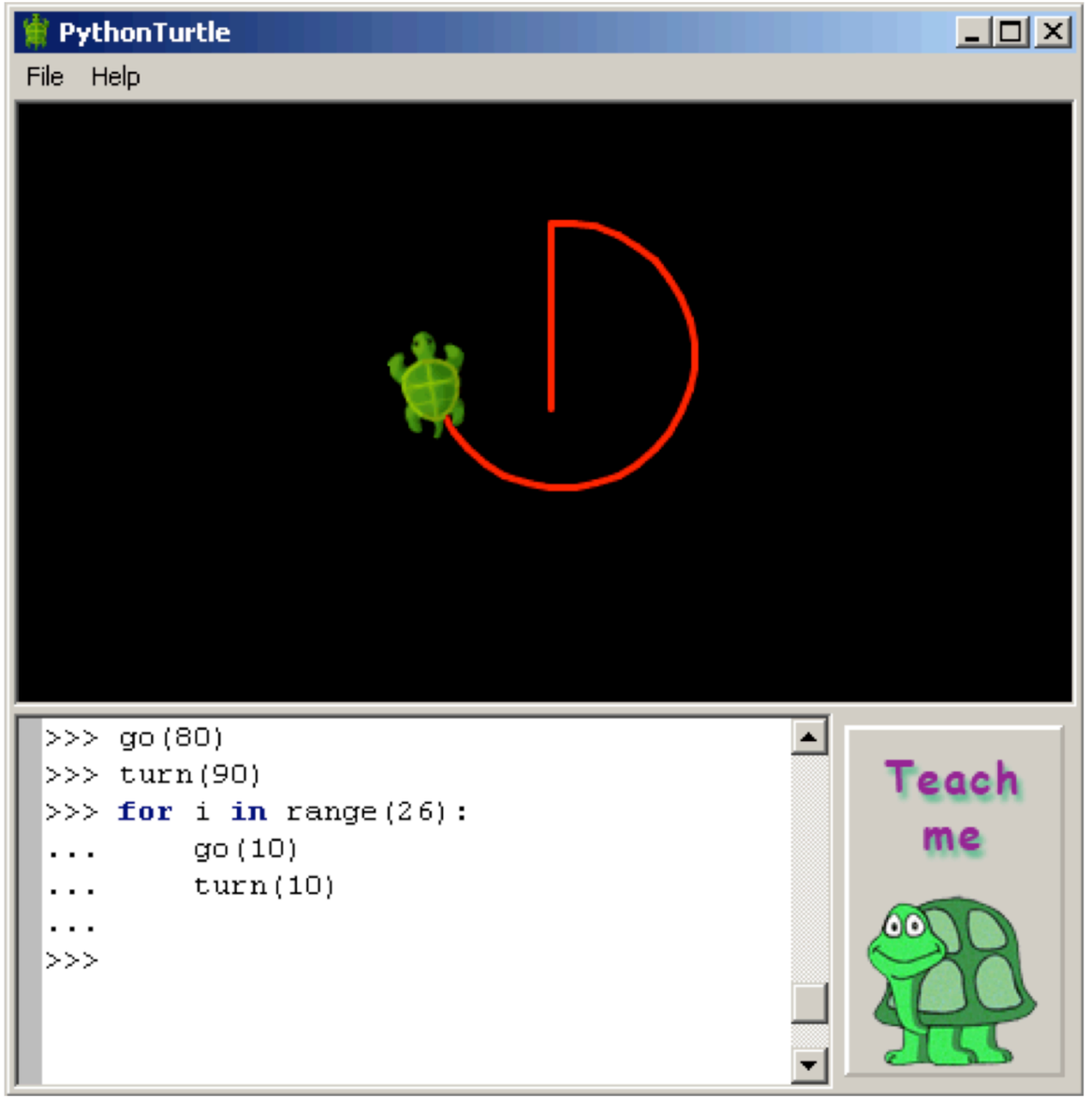
[9] Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books, Inc..


PythonTurtle
File Help
>>> go(80)
>>> turn(90)
>>> for i in range(26):
... go(10)
... turn(10)
...
>>>
Teach me

Maths & Programming

- Research groups have worked in this area for decades (e.g. MIT Media Lab, London Knowledge Lab)
- 1990s: computing classes shifted focus to use of office applications
- LOGO became seen as an "activity"[10] e.g. turtle graphics
- CT gained popularity after Wing's article in 2006

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[10] Agalianos, A., Whitty, G., & Noss, R. (2006). The social shaping of Logo. Social studies of science, 36(2), 241-267.

Aims & Research Questions

Aims

- We are Computer Scientists and STEM Educators
- Interested in:
  - How the learning of maths and CT are linked in the literature
  - Consequences for K-12 practice and preparation of teachers
  - The types of studies that have been conducted in this area (empirical vs non-empirical etc)

Research Questions

1. What peer-reviewed studies have been published from 2006 to 2016 in relation to Computational Thinking in K-12 educational contexts?
2. Do these studies link Computational Thinking to the learning of Mathematics, and in what ways?

Methodology

Methodology

- Arksey, H. and O'Malley[11] identified four reasons for conducting a Scoping Review, the 2 relevant to this study were:
  - “To examine, the extent, nature and range of research activity”
  - “To identify research gaps in the existing literature”

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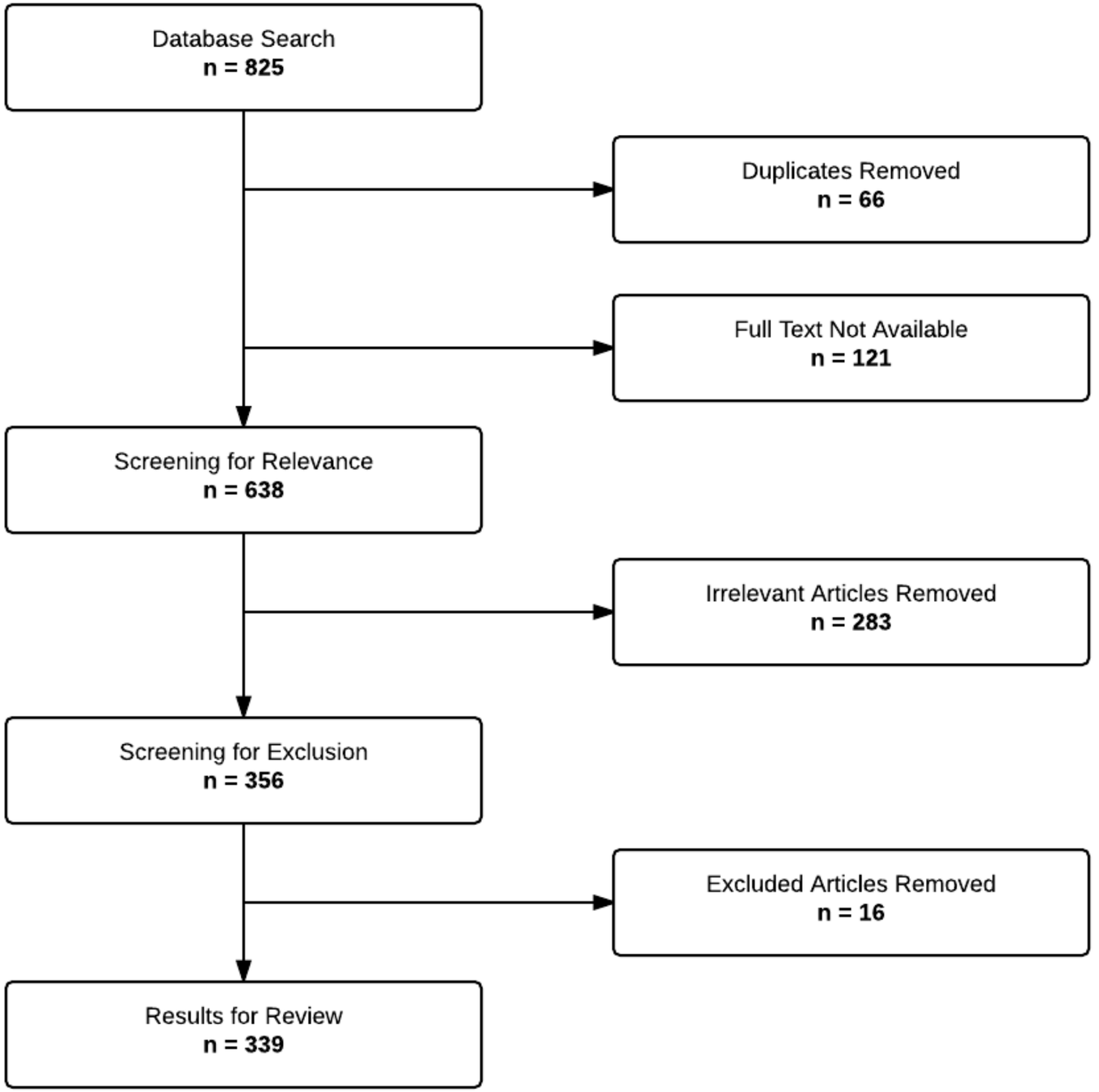
[11] Arksey, H. and O'Malley, L. (2005) Scoping studies: towards a methodological framework, International Journal of Social Research Methodology, 8, 1, 19-32.

Searching Databases

- Six databases searched: 4 multidisciplinary, 2 Computer Science focused
- Search term used: *"computational thinking" AND "school*" AND ("Primary" OR "Secondary" OR "High" OR "K-12"*
- Limited to studies published from 2006 to 2016
- Peer reviewed Journal / Conference Articles & Book Chapters

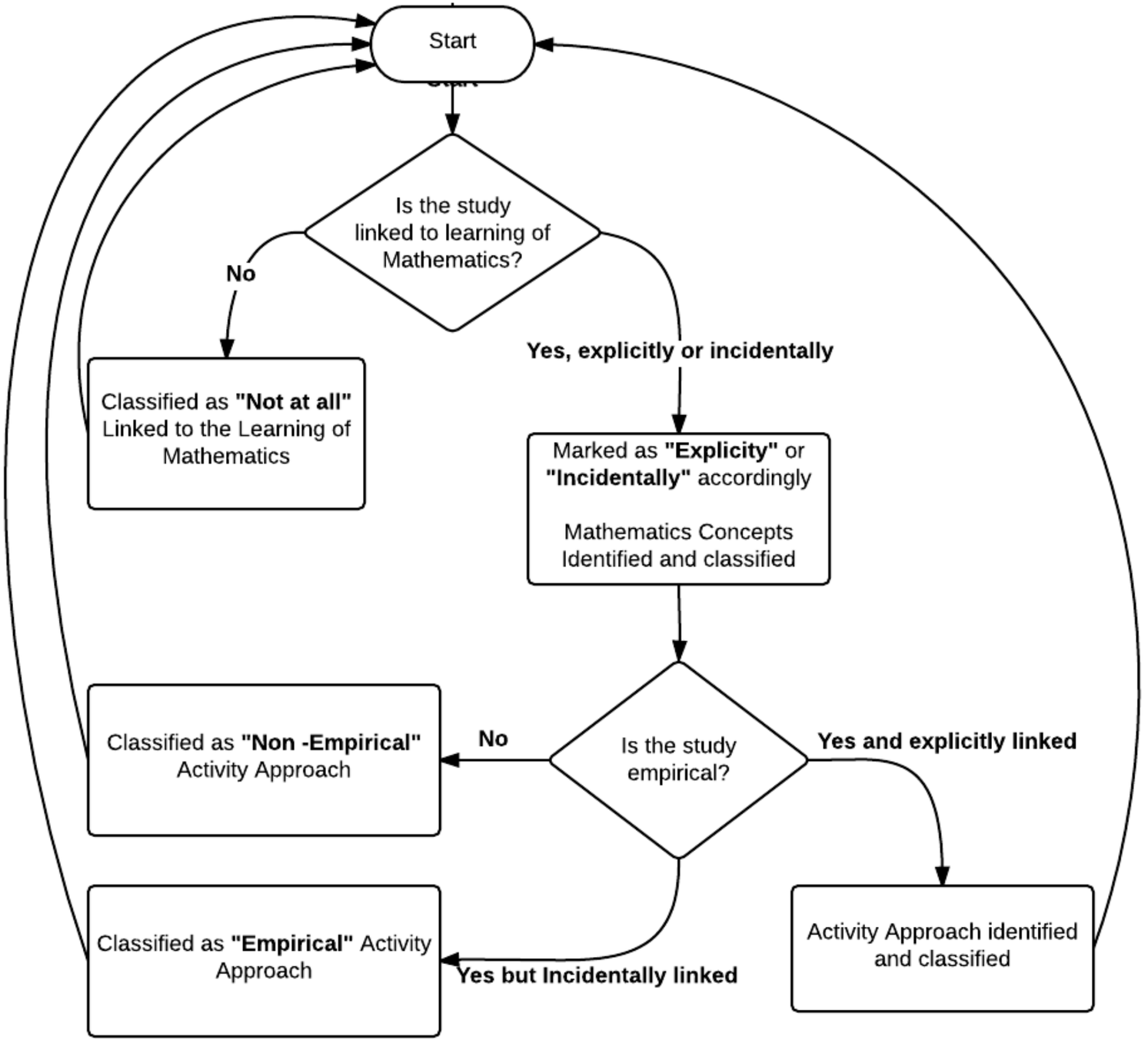
Searching Databases

Database	Number of Results
IEEE Xplore (CS focus)	253
Springer	236
Proquest	129
ACM Digital Library (CS focus)	104
ScienceDirect	69
EBSCO Megafile Premier	34
Total	***825***


Database Search
n = 825
Duplicates Removed
n = 66
Full Text Not Available
n = 121
Screening for Relevance
n = 638
Irrelevant Articles Removed
n = 283
Screening for Exclusion
n = 356
Excluded Articles Removed
n = 16
Results for Review
n = 339

Classification Process

- **Link to the Learning of Maths**
  - Not at All, Incidentally or Explicitly
- **Maths Concepts Present**
  - e.g. Geometry, Algebra, Statistics & Probability
- **Activity Approach**
  - Non-empirical, empirical, conceptual, procedural or both


Start
Is the study linked to learning of Mathematics?
No
Classified as "Not at all" Linked to the Learning of Mathematics
Yes, explicitly or incidentally
Marked as "Explicity" or "Incidentally" accordingly
Mathematics Concepts Identified and classified
Is the study empirical?
No
Classified as "Non -Empirical" Activity Approach
Yes and explicitly linked
Activity Approach identified and classified
Yes but Incidentally linked
Classified as "Empirical" Activity Approach

Link to Maths

- **Explicitly:** When researchers made a clear link between CT and maths
- **Incidentally:** Mathematics concepts present in study but no clear intention to teach these
  - e.g. creating games usually involves some Geometry
- **Not at all:** No evidence of mathematics concepts present in study

Maths Concepts

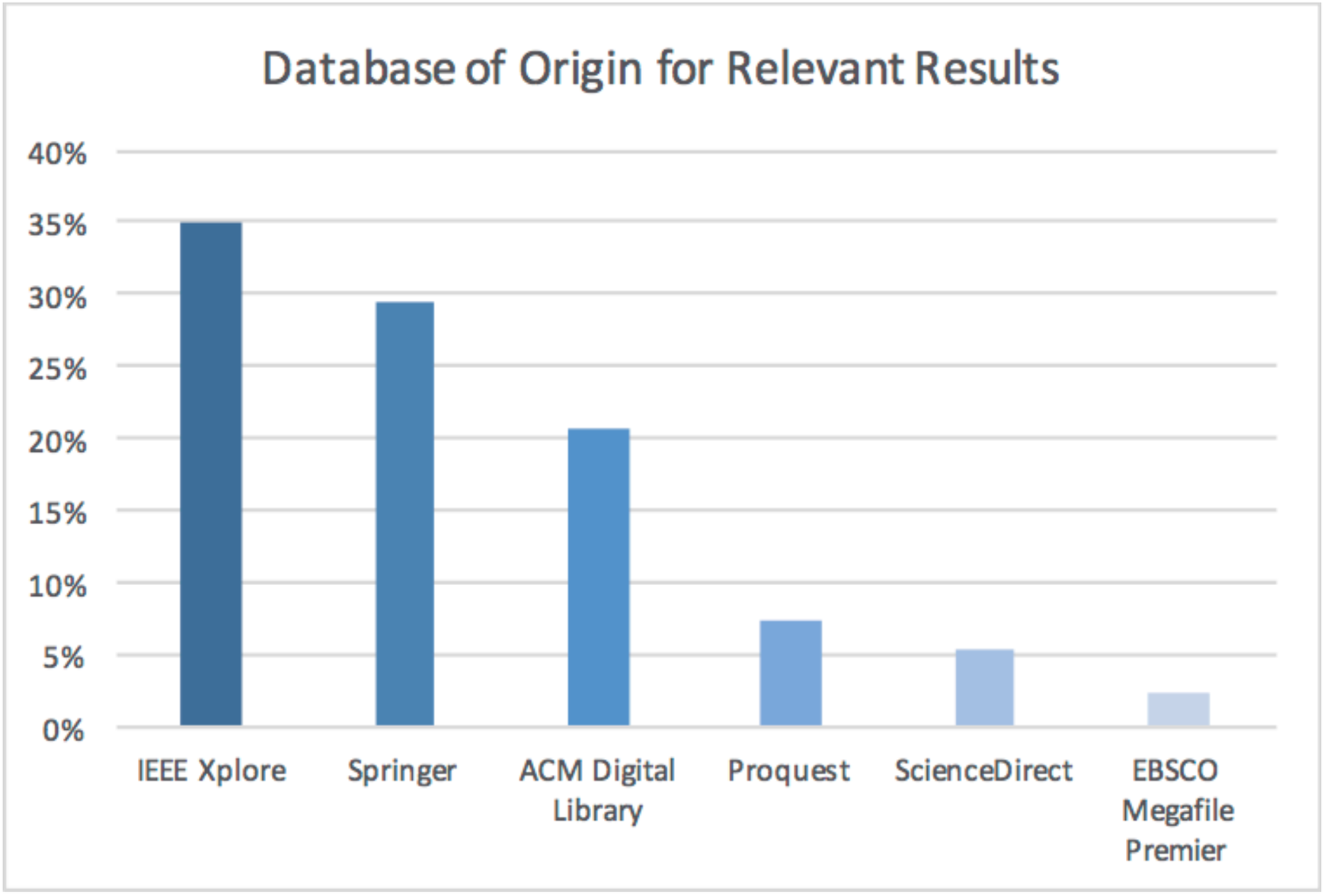
- **Numbers & Operations:** Counting, operations, number systems and fractions
- **Algebra:** Abstraction of numbers and equations
- **Measurement & Functions:** Ratios, proportional, linear, non-linear relationships
- **Geometry:** Shapes, Cartesian coordinates and area
- **Statistics & Probability**

Activity Approach

- For empirical studies:
  - **Conceptual:** understanding of relationships between concepts
  - **Procedural:** the application of rules, algorithms or procedures
  - **Both:** both of the above
  - **Not Clear**: type of knowledge imparted not clear

Results

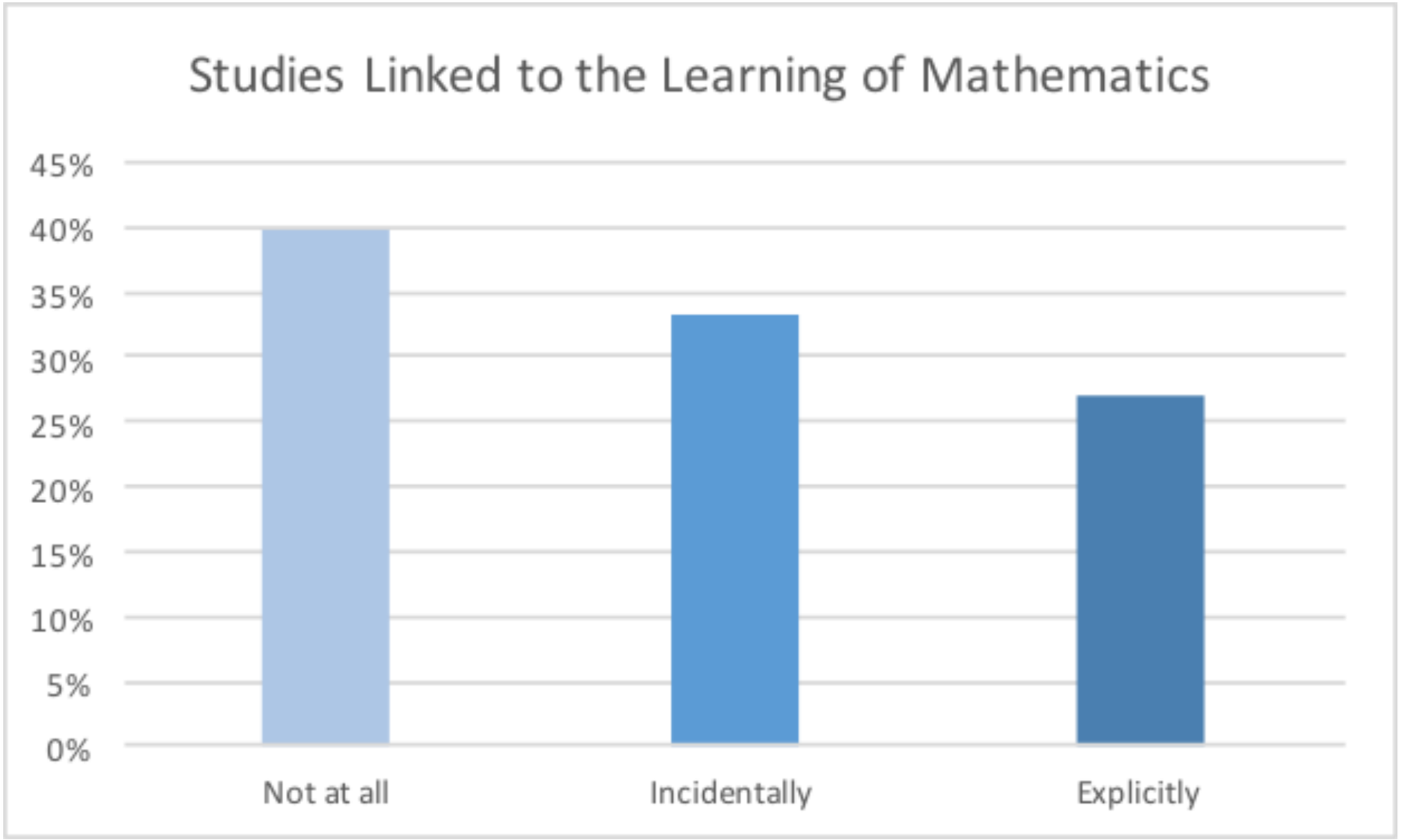
1. More than half of the reviewed studies originated from Computer Science focused databases


Database of Origin for Relevant Results
40%
35%
30%
25%
20%
15%
10%
5%
0%
IEEE Xplore
Springer
ACM Digital Library
Proquest
ScienceDirect
EBSCO Megafile Premier

Studies' Database of Origin

- Studies often conducted by Computer Science academics with an interest in Education
- Often focused on students' perceptions of Computer Science and related careers
- Often involved introducing Programming to students, e.g. as part of a summer camp

2. Studies that Explicitly Linked Computational Thinking and Mathematics Were Uncommon


Studies Linked to the Learning of Mathematics
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Not at all
Incidentally
Explicitly

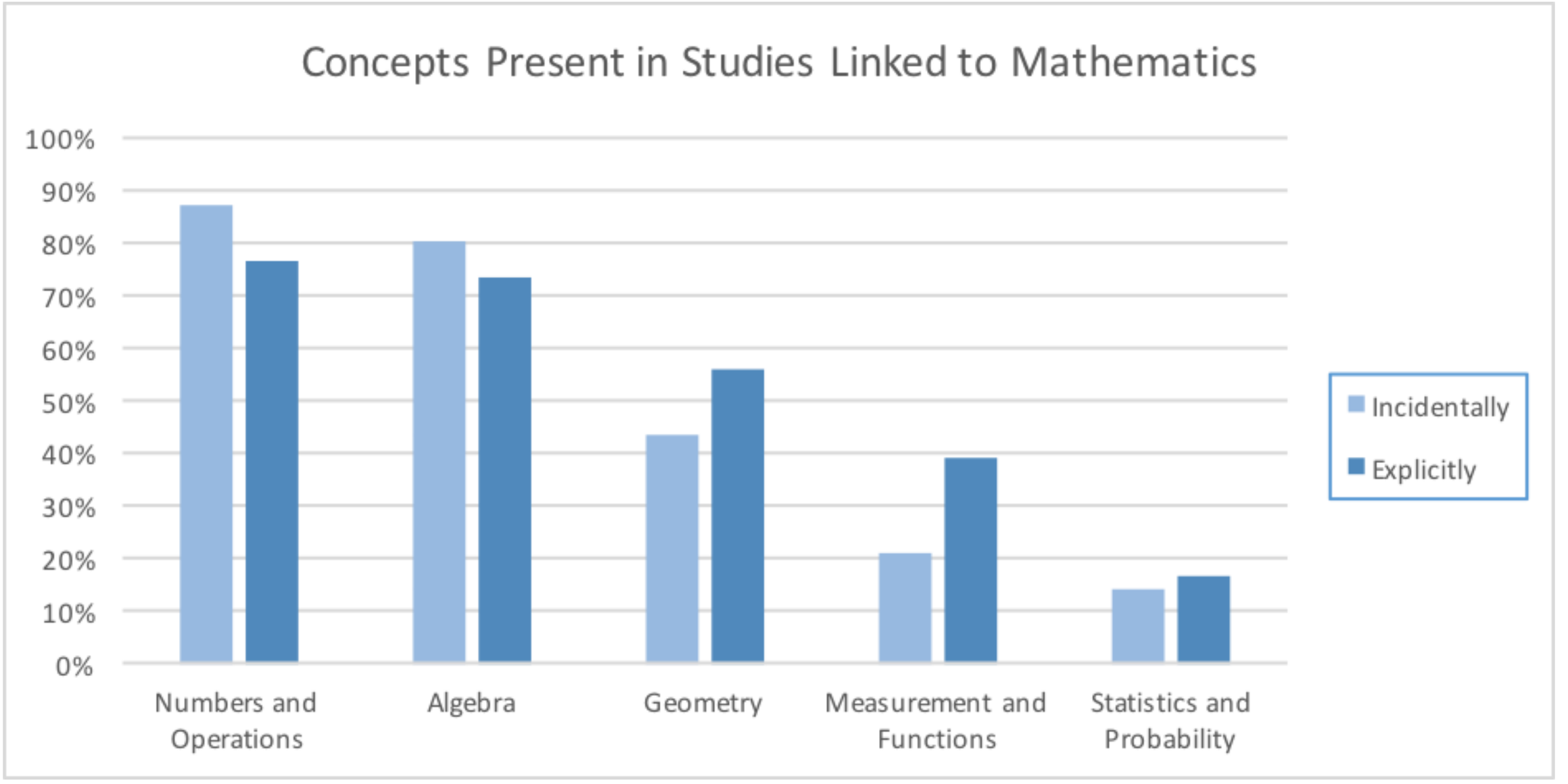
Link to Learning of Maths

- Studies with an incidental link more common than explicit
- Fundamental programming concepts often use numbers and algebra

```
var x = 5;
var y = x - 2;
// Next line will print 3
console.log(y);
```

- Studies with no link at all most common

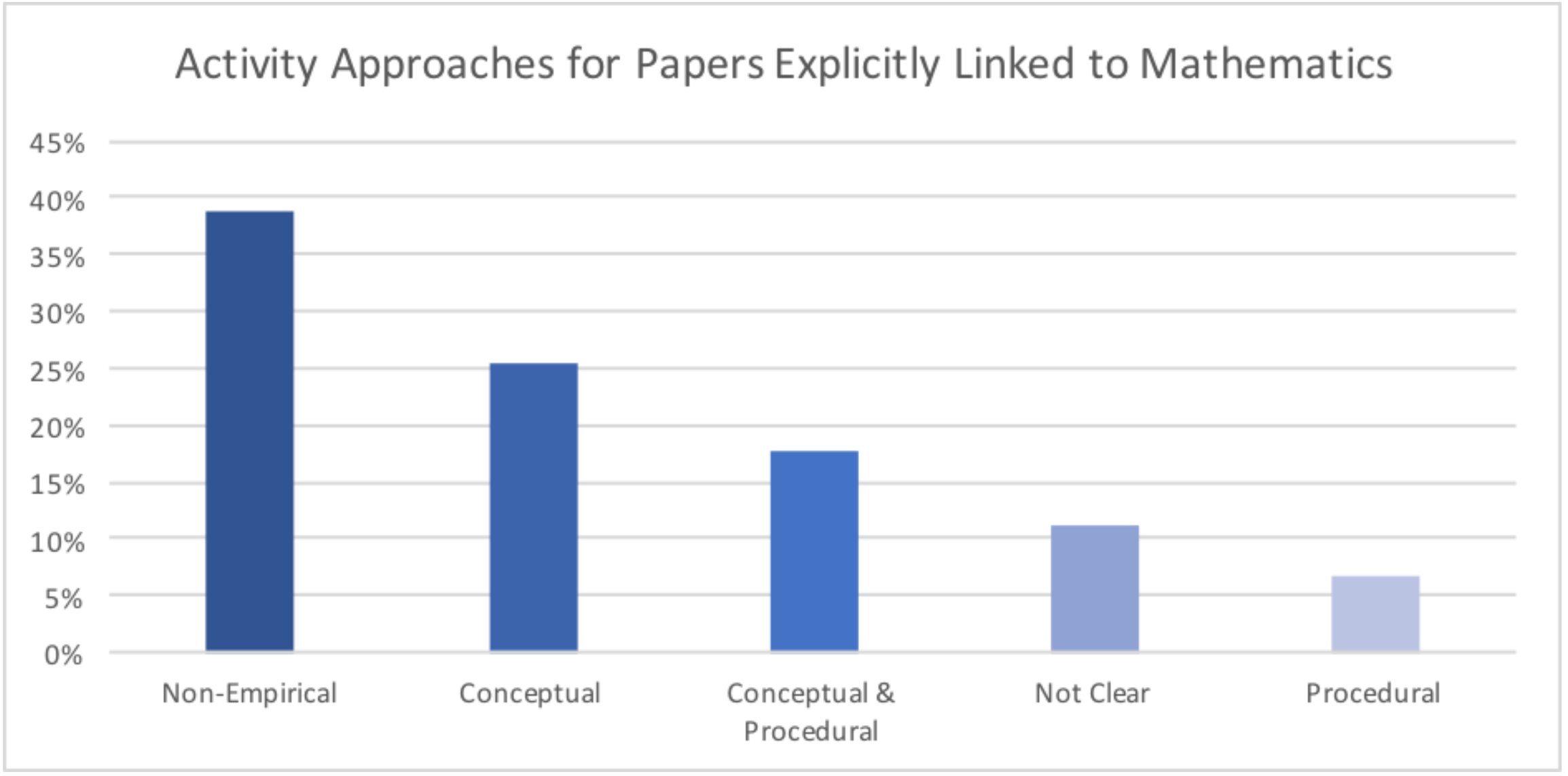
3. Numbers and Algebra Were the Most Common Concepts Present in Studies


Concepts Present in Studies Linked to Mathematics
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Numbers and Operations
Algebra
Geometry
Measurement and Functions
Statistics and Probability
Incidentally
Explicitly

Common Concepts in Studies

- *Numbers & Operations*, *Algebra*, *Geometry* were common and appeared together in studies involving:
  - Game design
  - Turtle graphics
  - Navigating Robots
- *Measurement & Functions* and *Statistics & Probability* weren't very common

4. Conceptual Activities Were the Most Common Empirical Approach Present in Studies


Activity Approaches for Papers Explicitly Linked to Mathematics
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Non-Empirical
Conceptual
Conceptual & Procedural
Not Clear
Procedural

Activity Approaches

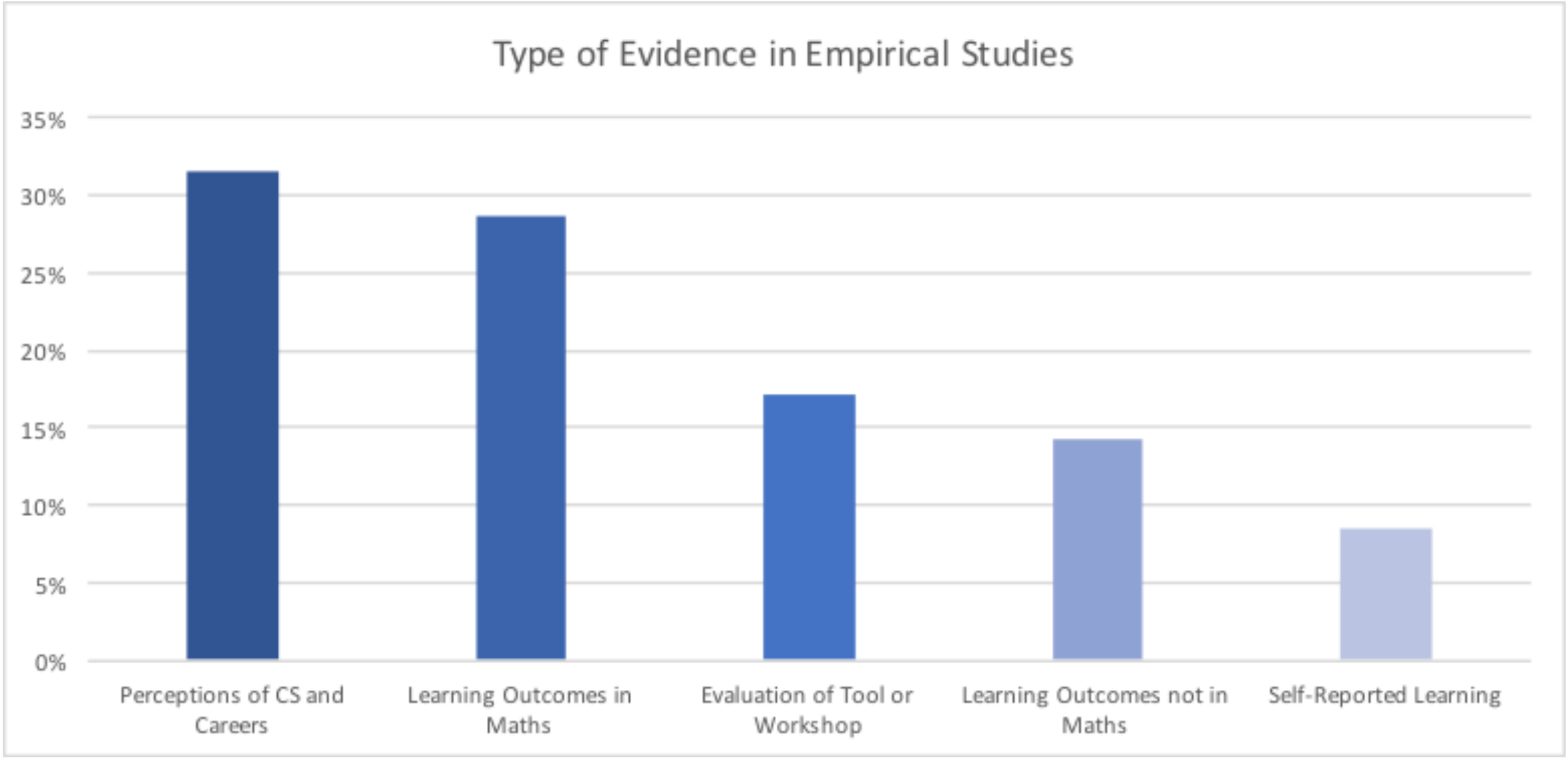
- Over a third (38%) of the studies were non-empirical
- Empirical studies often involved teaching conceptual understanding
- Particularly common in creating simulations and drawing shapes (e.g. turtle graphics)

5. Empirical Studies with Evidence of Impact on Student's Mathematics Learning Outcomes Were Rare

Methods in Empirical Studies

Research Methods	Number of Studies
Quantitative Only	20
Qualitative Only	18
Mixed Methods	15

- The 35 studies with quantitative methods (quantitative only & mixed methods) were examined and had their research design and type of evidence classified


Type of Evidence in Empirical Studies
35%
30%
25%
20%
15%
10%
5%
0%
Perceptions of CS and Careers
Learning Outcomes in Maths
Evaluation of Tool or Workshop
Learning Outcomes not in Maths
Self-Reported Learning

Evidence of Learning Outcomes

- Perceptions of Computer Science and careers common
- Only 10 of the studies reported participants learning outcomes in maths
- None of the studies involved the observation of long-term learning outcomes
- Only 2 studies had descriptive and inferential statistics, reported learning outcomes, and had a control and experimental group

Conclusions

Conclusions

- There's plenty of existing resources, such as CSUnplugged and Scratch, but there's not many concrete examples of how to use these effectively in maths in K-12
- There's a need to research approaches for supporting teachers, pre-service and in-service, integrating CT with maths
- There's a lack of rigorous research designs in the CT literature, particularly a lack of students' long-term learning outcomes in maths