Fluid Intelligence Doesn’t Matter! Effects of Code Examples on the Usability of Crypto APIs

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ABSTRACT
Context: Programmers frequently look for the code of previously solved problems that they can adapt for their own problem. Despite existing example code on the web, on sites like Stack Overflow, cryptographic Application Programming Interfaces (APIs) are commonly missed. There is little known about what makes examples helpful for developers in using crypto APIs. Analogical problem solving is a psychological theory that investigates how people use known solutions to solve new problems. There is evidence that the capacity to reason and solve novel problems a.k.a. Fluid Intelligence (Gf) and structurally and procedurally similar solutions support problem solving. Aim: Our goal is to understand whether similarity and Gf also have an effect in the context of using cryptographic APIs with the help of code examples. Method: We conducted a controlled experiment with 76 student participants developing with or without procedurally similar examples, one of two Java crypto libraries and measured the Gf of the participants as well as the effect on usability (effectiveness, efficiency, satisfaction) and security bugs. Results: We observed a strong effect of code examples with a high procedural similarity on all dependent variables. Fluid intelligence Gf had no effect. It also made no difference which library the participants used. Conclusions: Example code must be more highly similar to a concrete solution, not very abstract and generic to have a positive effect in a development task.

CCS CONCEPTS
- Security and privacy → Software security engineering. Usability in security and privacy; Cryptography.  
- General and reference → Empirical studies;  
- Human-centered computing → User studies;  
- Software and its engineering → Software libraries and repositories; Modules / packages.

KEYWORDS
Example Code, Intelligence, security, usability

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1 INTRODUCTION
Most software requires the use of cryptography for security purposes. Developers, who commonly are no security experts, must find out how to use cryptography Application Programming Interfaces (APIs) in their code. Finding and learning from examples for the usage of such APIs is one of the ways to make their programs work. Yet, there is little known about what makes examples from the documentation or sites like Stack Overflow helpful for developers or lead to misuse.

Such an approach falls under Analogical Problem Solving (APS) [4] in psychology. There are three dimensions of similarity between a target solution and a source analogy [3]: (1) Superficial similarity is given if the source analogy shares common general attributes like objects and characters. (2) Structural similarity is given if the source analogy shares causal relations like the same solution principle, the same obstacles, the same outcome or the same resources. (3) Procedural similarity regards how similar the procedures and operational details are that are required to implement the solution. Having only superficial similarity can lead to choosing unsuitable solutions. Hence, structural and procedural similarity are needed to support APS. Yet, not only the analogy itself is a factor but also the capabilities of the developer who relies on analogies to solve a problem. The most relevant capability is Fluid Intelligence (Gf) – the ability to reason and solve novel problems – because of its high correlation with analogical reasoning performance [7].

We designed a controlled experiment to test whether examples with different similarity and Gf of developers have an influence on the effectiveness, efficiency, satisfaction and created security bugs of performing a Java development task involving a crypto library done by novice programmers. Examples from CryptoExamples1 are our benchmark and were given the experiment group in addition to both groups being able to search the web for other examples. To control for the influence of a specific crypto library, we included Google Tink besides the Java Development Kit (JDK).

Acar et al. [1] conducted a controlled experiment with 256 Python developers who had to perform various tasks involving symmetric and asymmetric encryption. Their findings suggest that missing documentation, code examples and other functionality let participants struggle with the APIs. Mindermann et al. [6] looked at the usability of Rust cryptography APIs. They found that the crypto library designed to be more usable was slightly less usable for the experiment participants. A major complaint by the participants was missing documentation of and examples for the libraries. In summary, low-level APIs, problems with documentation and missing examples are reasons for misuse.

1https://www.cryptoexamples.com/
2 EXPERIMENTAL DESIGN

We had two independent variables that we manipulated in the experiment: The used cryptographic library (either JDK or Tink) and the used examples (either CryptoExamples or other found examples). Additionally, we measured the independent variable GF with Bochumer Matrizentest (BOMAT) advanced short [5], a non-verbal power-speed test.

The dependent variables are: The effectiveness (how much of the task was completed until the time limit was reached), efficiency (the time needed to finish the task or, in case of not finishing the complete task, 80 minutes) and the satisfaction (measured with the System Usability Scale (SUS) [2]). Furthermore, we measured the number of statically detectable security bugs in the final implementation.

The subjects of the experiment were 76 undergraduate students of a course on the introduction to software engineering at the University of Stuttgart, Germany. Participants were assigned to the following groups: (JO) Using the default crypto library of the JDK and not receiving the crypto example code. (JM) Using the default crypto library of the JDK and receiving the crypto example code. (TO) Using the Tink crypto library and not receiving the crypto example code. (TM) Using the Tink crypto library and receiving the crypto example code.

The only experiment task was to encrypt a string using the Advanced Encryption Standard (AES) and decrypt it for the participants with no integrity” followed by “Electronic Codebook (ECB) mode (TO) Using the Tink crypto library and not receiving the crypto example code. (JM) Using the default crypto library of the JDK and receiving the crypto example code. (TM) Using the Tink crypto library and receiving the crypto example code. (TO) Using the Tink crypto library and not receiving the crypto example code. (TM) Using the Tink crypto library and receiving the crypto example code.

In a regression analysis of all involved factors, we found a negligible influence of GF with β values close to 0. Only the usage of CryptoExamples showed statistically significant, large effects.

4 LIMITATIONS

Allowing the participants to use the web restricts our control on what sources they use to help them in their tasks. Participants of all groups could use the web and search for examples on the web, including the experiment group. We see it as necessary, because it is closer to development in a practical setting. Yet, it introduces the threat that participants from the control group used examples with a procedural similarity comparable to CryptoExamples (or CryptoExamples directly). To mitigate this threat (1) we classified the other viewed examples and compared them to the provided examples from CryptoExamples. (2) After the experiment, we reassigned participants based on their activity log (if they found and used CryptoExamples). During this discovery, we found no other used example that has a comparable procedural similarity as CryptoExamples. Differences in other categories, except for security, are not as clear as for procedural similarity.

We used first and second year students with some programming experience and little to no experience with cryptography. Hence, we expect that the results can be generalized to other programming beginners or even professionals new to using cryptography libraries.

5 CONCLUSIONS

Our results suggest that providing analogical solution with high procedural similarity can be an important factor for being effective, efficient and satisfied in using cryptographic libraries while creating few security bugs. To our surprise, the effect of GF was very small. We see this positive, because it seems that successful usage of the cryptographic libraries with the help of examples does not depend on the GF of the developers. This means that there is no internal and stable factor that prevents developers from successful use. Improving solution examples is probably much easier than improving the fluid intelligence GF of developers.

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