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Empowering women to code: Playful learning with Karel

Stephen Tierney, Alison Wong
The University of Sydney Business School

Programming skills are essential across STEM and data-intensive fields, yet many students, particularly women, experience anxiety and lack confidence in their coding abilities. To address these issues, we developed an extracurricular coding challenge using Karel the Robot for undergraduate and postgraduate business students enrolled in introductory data science units. We conducted a mixed-methods study to evaluate the effectiveness of the intervention. Participants who engaged with the challenge reported an increase in positive sentiment towards programming and confidence. Notably, women exhibited larger gains in confidence than men, despite facing the stereotype about gendered ability. These findings indicate that playful and low-stakes environments can empower underrepresented learners.

Keywords: Women, Code, Programming, Playful, Karel, Business, STEM

Background

Programming has emerged as a vital skill across science, technology, engineering and mathematics (STEM) and data-intensive fields. It is now an integral part of nearly every scientific and technological endeavour. Programming empowers individuals to transform vast, complex datasets into meaningful insights, uncover hidden patterns, and make data-informed decisions. Moreover, the rapid advancement of machine learning (ML) and artificial intelligence (AI) has further elevated the importance of programming. Those with strong coding skills are uniquely positioned to leverage cutting-edge ML algorithms and can accelerate their productivity with AI tools such as large language models. Programming's influence is no longer confined to computer science and as a result, programming education can no longer be confined to the discipline of computer science. Programming education must be inclusive, interdisciplinary, and accessible to students from a wide array of academic and cultural backgrounds.

The technical nature of programming is well-documented as a source of intimidation and significant anxiety for many students (Koohang, 1989; Chang et al., 2024;). In unit evaluations, our students have consistently identified programming as one of the most difficult aspects of their coursework. We believe this feedback to reflect both a lack of confidence and a genuine struggle to grasp the material.

An important issue to the authors is the gender gap in computer science and programming education, which is a long-standing and well-known phenomenon (de Carvalho et al., 2020; Kiehlbauch et al. 2024) and can be attributed in part to lower levels of confidence amongst women (Bernstein, 1991; Hoegh, 2009). To date, an estimated 50% of research on the gender gap in programming education and interventions has focused on high school level students, with only 37.5% at the university level (Perez-Felkner et al., 2024). The present study therefore serves to add weight to a relatively under researched aspect of programming education.

The authors teach data science courses within a School of Business, a context not traditionally viewed as part of the STEM canon, yet one that is undeniably STEM in both content and complexity. This has led to a surprising confluence, quite different from most STEM education, where we have equal gender representation and students who enter without a strong inclination toward programming.

Recognising the gender issue, one of our objectives as educators is to make programming more approachable and engaging for all learners. To address this objective, we introduced a low-stakes, extra-curricular programming challenge using Karel the Robot (Pattis et al. 1995), an educational tool originally developed at Stanford to facilitate introductory programming education. Our approach aligns with Whitton's (2018) model of playful pedagogy with tools (the robot world), techniques (quest like challenges) and tactics such as completion rewards.

Karel

Karel is a virtual robot that students control through code, navigating and interacting with a 2D grid-based environment (see Figure 1). Karel can perform a limited set of primitive actions in the word such as moving forward one space, turning left, collecting or placing an object to or from its bag and sensing the environment such as checking if there is a wall in front or which direction it is facing. In the recently developed Python version of Karel, which was used in our initiative, only a subset of Python's functionality is available. Notably students cannot create variables, and all program data and memory must be stored or represented by the objects in Karel's world.

The immediate visual feedback of Karel and constrained environment provides an accessible entry point into programming. When controlling the robot with code students are, often unknowingly, translating abstract programming concepts into concrete actions.

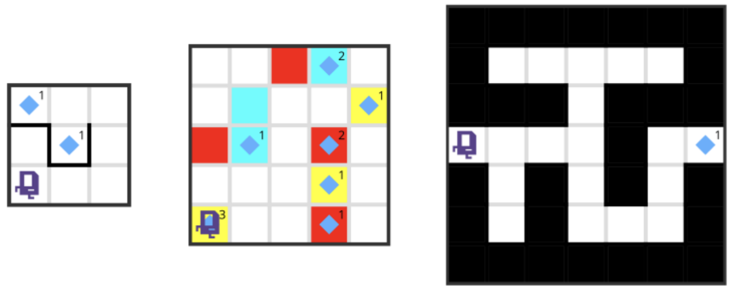

Figure 1. Three examples of different Karel environments representing a 3x3, 5x5, and 7x7 grid world. Karel is position in the bottom left of the first two worlds and in the centre left of the third world. These worlds contain objects (blue diamonds) and coloured squares. The solid black lines in the first world indicate walls that Karel cannot pass through. While these examples illustrate relatively simple problems, the Karel Challenge introduced students to much more complex scenarios, requiring advanced computational thinking to solve problems within grid worlds as large as 29x29.

Karel Challenge

Inspired by the efforts of others (Bogdanovych et al., 2016; Piech, 2021) we created a low-stakes and extra-curricular programming challenge using Karel. Our decision to use an extracurricular activity was driven by time constraints in our courses, as well as research showing that such activities help women build personal connections to the field and to their peers (Altin & Mühling, 2024).

The Karel Challenge was a 5-week challenge that did not contribute to grades; however, students were rewarded for sustained participation with certificates and Karel keychains. The top 10 performing students in each unit were further awarded with t-shirts and progressively larger Karel trophies. We ran separate undergraduate and postgraduate streams in our introductory data science courses.

Each week we released a set of 5 problems to students, which they completed on their own time. We designed the problem sets so that students could apply recently introduced programming concepts to solve the next problem set. Students were encouraged to collaborate and discuss the problems with their peers with the intention to foster collaboration. Teaching staff were instructed to intervene as minimally as possible.

Research Questions and Method

Our research question was: “Does Karel improve students’ attitudes towards programming?” More specifically, after participating:

- are students more confident in their ability to write code?
- have student’s perceptions changed about gender capability?

To evaluate the effectiveness of the Karel challenge we conducted a mixed-methods study consisting of pre and post Likert scale web surveys and in-person focus groups during semester 2, 2024 The survey questions were drawn from a validated question bank covering confidence, interest, gender, employment and professionalism constructs (Hoegh, 2009).

Only students who participated by completing at least one problem were invited to participate in the post survey and focus groups. The number of students who completed the surveys are shown in Table 1. Nonparticipants were invited to complete a separate survey asking why they chose to not participate. As part of our human ethics application, we requested and were granted access to personal metadata collected by The University of Sydney (2024/HE001048).

Table 1. Student participation rates by male (M), female (F) and non-binary (X) genders.

	Undergraduate			*Postgraduate*		
	M	F	X	M	F	X
Total students	12	84	0	295	368	6
Paired pre-post survey respondents	19	18	0	37	45	1

Findings and Discussion

Our results show that Karel can positively influence student confidence and attitudes towards programming. Notably responses in the focus group and to Karel specific questions in the survey showed strong evidence for the effectiveness of the intervention. On the other hand, the responses from the validated question bank show mostly no statistically significant changes, however we believe this to be for reasons unrelated to the intervention, which we discuss below.

Confidence in Programming Ability

Karel-related questions KQ1, KQ4 and KQ6 in the post-survey related to attitude towards programming and completing the challenges (see Figure 2). Overall, students were positive about their experience with the majority agreeing that they felt more positively about programming. One female student reported, ‘*I think Karel may be a lot of fun... I also haven't read code before. I used to think code is very boring just about some math ... I'm not sure. But when I found that I can make the Karel move I feel very interesting, and I'm so proud of myself... Although some condition is a bit challenging I still feel it's very fun, and I think I will make it as my future career.’*

When asked about how Karel impacted their confidence a female student reported, ‘i*n Vietnam, where I'm from... there's a saying that like, if you study programming or IT like you must have like a bullet in your brain... not a lot of girls actually study that field. But after Karel, I'm like, yeah, it's quite fun. It's not actually not that hard’*. This change in attitude was common among the women in the focus group.

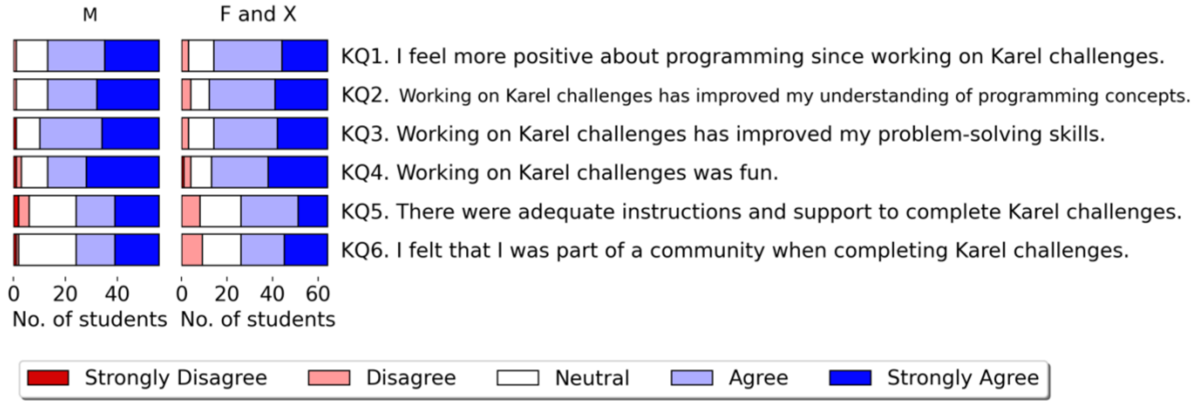

Figure 2. Responses to post intervention Karel-related Questions (KQ1-6) by male (M) and female and gender diverse (F and X) respondents. These questions were not included in the pre survey.

Students also reported that Karel made them feel part of a learning community. One student mentioned that it gave her a chance to connect with other students in her major, while another student shared that he appreciated the opportunity for peer learning, noting that students would meet to discuss solutions, exchange ideas for approaching problems, and assist one another in identifying issues in their code.

Responses to pre-post questions drawn from the validated question bank (Hoegh, 2009) on attitude showed no statistically significant change in responses in the female and gender-diverse group (Bonferroni corrected Bhapkar tests). We believe that the stark difference in responses between the Karel related and the generic survey questions is likely due to students compartmentalising their positive Karel experiences. In other words, they view Karel as an isolated programming experience and the skills or experience gained are not immediately transferrable to “real” programming.

This sentiment was carried by a few focus group participants. This perception contrasts with the fact that many students developed complex Python programs to control Karel. It appears that Karel’s user-friendly interface may have unintentionally masked the complexity of the tasks, leading some students to overlook the sophistication of their code. As a result, they underestimated the real-world programming skills they were developing, despite engaging with challenging logic and writing substantial Python code.

Perception of Gender Ability

A concerning trend in our results is that there is a persistent minority of students, both male and female, with the perception that women do not have the same natural ability as men when it comes to programming, which was reflected in responses to gender construct questions. This effect may be partially due to acquiescence bias; however, we believe this to be an unfortunately true effect. This is despite the overwhelming empirical evidence even within the Karel challenge where our results show that women perform as well as men on programming problems. Women are easily observed to be as competent as men, with the top woman and man having a negligible difference of only 1 point. A two-sample Kolmogorov-Smirnov test on the points achieved by men and women yields a p-value of 0.6665, which is a strong indicator that the samples are identically distributed and that their performance is the same.

Limitations and Future Directions and Conclusion

The presented results are limited to semester 2, 2024 since our ethics approval only permits access once each semester’s results have been finalised. This project extends into 2026 so we will be able to build our evidence base and make semester level comparisons. Moreover, the student level metadata available to us also includes many variables such as student entrance scores and socio-economic indicators that will allow us to more precisely determine the effect of Karel by controlling for a student’s academic ability and background.

To determine if the findings generalise to other contexts, we have recruited a large introductory programming unit for semester 2 of 2025. This unit will provide evidence from the context of a typical programming unit with much lower numbers of women and non-binary enrolments.

We note that our study is subject to several biases. There is a self-selection and sampling bias since students were only invited to the post-survey and focus groups if they had participated, which weakens generalisation of our findings. However, since this is a voluntary program, there will always be many “unreachable” students, which we cannot influence. Furthermore, we believe there to be an acquiescence bias in our results as students may be more likely to respond “Strongly Agree” or “Agree” because they think it's the answer we are looking for and it is the first and fastest option to select on the surveys. In the future we plan to include control questions that are logically negated to control for acquiescence and more precisely detect changes in attitude.

Overall, our initial findings suggest that playful, low-stakes programming environments such as Karel can positively influence student confidence and attitude towards programming. However, our study and the results presented have several limitations, which we aim to address in future work.

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