Institution: University of Cambridge

Unit of Assessment: 11 Computer Science and Technology

Title of case study: Isaac Online Platforms: improving A-Level grades, access to top universities, teacher workload, and the take up of Physics by non-traditional and under-represented students

Period when the underpinning research was undertaken: 2000-2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Alastair Beresford	Professor of Computer Security	1 Jan 2007 to present
Andrew Rice	Professor of Computer Science	1 Jan 2008 to present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

A team at the Department for Computer Science and Technology at the University of Cambridge have developed novel technologies, tools and processes to transform online interactive and blended learning for 14-19 year-old students and teachers. The approach has been applied to learning physics through the Isaac Physics platform and, more recently, to learning Computer Science. The impact of this research has been to:

- improve grades and University entrance outcomes for A-level students studying physics. Engaging with the Isaac platform can significantly raise a cohort's A level grades and increase their attainment of places at Russell Group Universities. This contributes towards government priorities to increase STEM graduates to meet the current skills shortage.
- support students from non-traditional HE backgrounds and engage under-represented groups like women in Physics. Approximately 21% of the current A-level cohort are women, but over the past 6.5 years 34-36% of Isaac Physics online users have been women.
- reduce teachers' workload and contribute to high quality physics lessons. Teachers using Isaac Physics report an average reduction in workload of 3.8 hours per week, freeing up time for the development of skills and resources. The School Standards Minister, Nick Gibb, commented in 2018 that "Isaac Physics…has already helped thousands of teachers to deliver high quality physics lessons".
- engage 30% of all A level computer science students in England through the Isaac Computer Science platform

2. Underpinning research (indicative maximum 500 words)

Professor Andrew Rice, an expert in programming and software engineering, and Professor Alastair Beresford, an expert in computer security and mobile systems, observed that students arrived at the University of Cambridge with very diverse backgrounds in programming, and therefore the content and pace of lectures which might be suitable for one student were unsuitable for another. As a result, Beresford and Rice developed new online methods and technologies to enhance the teaching of computer programming at the University.

Supporting the teaching of the computer language Prolog

Using their joint expertise in programming languages and tools in the sciences, Beresford and Rice wrote software and produced short videos focused around the undergraduate course on teaching programming in Prolog. However, they wanted to go beyond the passive viewing experience and encourage more interaction and feedback tailored to an individual student's understanding. To achieve this, they developed the first version of the Interactive Lecture Video Platform (ILVP) that supported in-video quizzes with immediate feedback on numerical and

multiple choices answers, and that supported a variety of viewing approaches (e.g. once-through, twice-through, section repeat, skipping).
In 'Investigating Engagement' [R1], Beresford and Rice analysed how students used the video and quiz feedback to test their knowledge, skipping content they were familiar with and revisiting more challenging content. The statistics gathered by the platform demonstrated that students made significant use of non-linear playback for both learning and revision. This data was complemented with semi-structured interviews and online surveys to analyse the effectiveness of this new method of delivery. The data showed a high level of engagement: students viewed over 80% of the videos on average. Of those that viewed videos at least once, they attempted over 80% of the embedded multiple choice and text entry questions. The less popular questions were thought to be due to an increased difficulty (later addressed through hints below), and an over-questioning (once every two minutes) on one video. A rate of one question every eight minutes seemed acceptable. The analysis of student questionnaires also strongly suggested that the questions should be designed with a variety of student motivations in mind, including Completionism, Challenge Seeking, Feedback and Revision. Since 2012-2013, the Prolog course has been taught using this new style of teaching, and in 2014 Rice and Beresford won a Cambridge Pilkington Prize for a substantial and excellent contribution to a teaching programme within the University.

Expansion to Physics

In 2013, the Department of Physics at Cambridge University were bidding for funding from the DfE to improve physics problem-solving in English schools, with the intention of encouraging more students to take STEM subjects to fill the recognised skills gap and shortage of good physics and maths teachers. Based on the success of the Prolog course, Professor Mark Warner and Dr Lisa Jardine-Wright from the Department of Physics met with Rice and Beresford to discuss their experience with online platforms for what was to become the Isaac Platform. Rice and Beresford's initial work on ILVP was a useful starting point, but significant new features were required to deliver an interactive problem-solving platform for physics.

Equation entry and feedback on structure and correctness.

In particular, interactive learning of the core mathematics underlying the physics teaching would require the entry and parsing of equations. In 2015 Rice, Beresford and their colleagues created a new tool for the platform, *Equality*, for equation entry using free-form layout of components drawn from a palette of symbols. This was designed to enable learners to manipulate the structure of their equations easily on both desktop and mobile environments, and to minimize the amount of experience required to use the tool [R2]. In particular, it emphasized the ability to easily revise the structure of equations after entry, while remaining machine-readable for effective feedback. Later work added the ability for the feedback software to evaluate the structure of answers as well as their mathematical correctness, in order to provide better feedback on aspects such as simplification or factorisation [R3].

Hints

Early work [R1] had indicated that the more difficult questions were attempted less often. This led the group to investigate hints as a form of scaffolding for users of Isaac Physics in 2016 [R4]. Hints were classified in to five main types (Concepts, Information, Diagrams, Equations and Videos), and student behaviour was analysed to determine common patterns of usage, including motivations such as Decomposition, Correction, Verification and Comparison.
The results of this research was then used to provide students with more effective revisions and feedback, so that the more difficult physics questions become less intimidating and more flexible.

Privacy-aware data sharing

Online educational tools often generate learning data, and sharing such data between tutors and students can often improve learning outcomes. However, too much data sharing may put off the less confident students. For example, the number of incorrect attempts at the in-video quizzes is not made known to teachers so that students are encouraged to experiment and learn from the feedback. To make data sharing more palatable to students, the group investigated the

transparency and user control aspects [R5]. The developed approach uses tokens through which students may grant (and revoke) access to their latest answers, to individually identified tutors. This gives the students control over their learning data, and helps to build trust in their tutors, particularly when those tutors are not provided directly by their teaching institution.

Overall
These research advances work together to provide Isaac Physics with a powerful and easy-to-use platform combining the interactive video learning with flexible quizzing, immediate feedback, effective hinting, and straightforward revision. In September 2019, the Isaac Computer Science platform, which uses the same underlying technology found in Isaac Physics, was launched.

3. References to the research (indicative maximum of six references)
All research outputs marked with * have been through a rigorous peer-review process:

*** [R1].** Stephen Cummins, Alastair R. Beresford, Andrew Rice, "Investigating Engagement with In-Video Quiz Questions in a Programming Course," IEEE Transactions on Learning Technologies. Volume 9 Issue 1, p. 57-66, 2016.
https://ieeexplore.ieee.org/document/7122326
*** [R2].** Stephen Cummins, Ian Davis, Alastair R. Beresford, Andrew Rice, **"**Equality: A Tool for Free-form Equation Editing." Proceedings of the IEEE 15th International Conference on Advanced Learning Technologies, p.270-274, 2015.
https://ieeexplore.ieee.org/document/7265324
*** [R3].** Andrea Franceschini, James P. Sharkey, and Alastair R. Beresford. 2019. "Inequality: multi-modal equation entry on the web." In Proceedings of the Sixth (2019) ACM Conference on Learning @ Scale (L@S '19). Association for Computing Machinery, New York, NY, USA, Article 12, 1–10.
https://doi.org/10.1145/3330430.3333625
*** [R4].** Stephen Cummins, Alistair Stead, Lisa Jardine-Wright, Ian Davies, Alastair R. Beresford, Andrew Rice, "Investigating the Use of Hints in Online Problem Solving", Proceedings of the 3rd ACM Conference on Learning @ Scale, p105-108, 2016
https://dl.acm.org/citation.cfm?id=2893379
*** [R5].** Stephen Cummins, Alastair R. Beresford, Ian Davies, Andrew Rice, "Supporting Scalable Data Sharing in Online Education," Proceedings of the 3rd ACM Conference on Learning @ Scale. p.97-100, 2016.
https://dl.acm.org/citation.cfm?id=2893376

4. Details of the impact (indicative maximum 750 words)

The Isaac Physics platform, based on the Cambridge group's research, is playing a crucial part in transforming physics teaching. It has achieved impressive reach: a quarterly report to The Department for Education (DfE) at the end of August 2019 showed that, across all year groups, there were 55,481 active users of Isaac Physics (206,570 registered users), of whom 7,603 were teachers [E1]. Currently more than 3,600 schools participate, many with over 50 students registered. Monthly, 28,000 students and 1,300 teachers use the platform with daily peaks of 145,000 problems answered [E2].

In relation to A-level physics students in UK schools specifically, over the period August 2017 to January 2018, there were 11,604 Isaac Physics users in year 12, and 6,758 in year 13 [E3 page 13]. Since roughly the same number of students study A level physics in years 12 and 13 in the UK overall (around 36,000 students in each year group) [E4], this equates to at least 25% of the A-level cohort being users of Isaac Physics [E3, page 13].

The significance of this impact is described below:

Impact 1: improving grades and University entrance outcomes for A-level students studying physics.

As a result of a collaboration with the UCAS STROBE service, the Isaac Physics user cohort was compared with 500 non-Isaac Physics cohorts, matched to remove potential biases, including demographic, GCSE grades, gender, and ethnicity. The analysis found that results at schools which actively engage with the Isaac platform show an improvement equivalent to 40% of the cohort raising their grade from C to B [E3, page 3]. Furthermore, when compared with non-users, Isaac Physics students were very significantly more likely to apply to, receive an offer from, and accept a place at high tariff universities. The correlation between the amount of Isaac activity and achievement of predicted grades was strongest for students applying to Russell Group universities, showing that using Isaac Physics improves chances of a place at leading universities [E3]. When asked, 74% of students agreed or strongly agreed that the Isaac platform helped them to improve their physics grade, and 75% said it helped them become more confident in physics [E3].

Impact 2: supporting students from non-traditional HE backgrounds and under-represented groups in Physics:

Physics students from non-traditional HE backgrounds may be under-supported by their schools, teachers or families, who are insufficiently experienced with the requirements of HE entry. The Isaac platform provides access to many of the resources that these students are missing. The technology enables them to self-study by providing hints and online tutorials, and gives them direct access to subject specialists. Progression in difficulty allows students to continually challenge themselves. One student wrote: "When I started in November 2016 I was doing level 1-3 questions, sometimes even struggling with these. Now I am frequently tackling level 4-6 questions, on topics that I have self-taught through the Isaac platform. That alone is testament to how much progress I have made thanks to this site" [E3].

Under-represented students are those whose participation in physics is less than half the level that their group size would merit, irrespective of HE backgrounds. Approximately 21% of the current A-level physics cohort are women, but over the past 6.5 years, 34-36% of Isaac Physics online users have been women [E2]. "Fear of failure" is a well-documented issue for under-represented groups, particularly women [E5]. The Isaac platform has been designed and built as a low stakes, high-trust environment to enable such students to develop confidence, realise that getting things wrong is part of the learning process, and that reflection leads to progression. Typically, students take three attempts to get questions right, demonstrating a level of resilience and confidence in the process.

The value of the online learning platform and the project more widely to improving student access to Physics has been recognised by DfE, who awarded the project GBP6.3 million in 2014, and a further GBP1.05 million in 2018. The School Standards Minister, Nick Gibb, said of the funding announced in 2018: “As part of our modern Industrial Strategy, we are focused on helping young people improve their knowledge and skills in science, technology, engineering and maths. Entries to A Level physics have increased by 18% since 2010 but the Government wants to see even more young people – especially girls and those from disadvantaged backgrounds – pursuing sciences” [E6].

The 2019 Lawrence Bragg Medal and Prize from the Institute of Physics was awarded to Dr Lisa Jardine-Wright and Prof Mark Warner (the Physicists co-directing the project) in recognition of the scale and reach of Isaac Physics. The award recognised that “this radical, mass-scale programme harnesses technology to help all students, especially those exposed to the national shortage of physics teachers with consequent social disadvantage in entering STEM at university” [E2].

The Ogden Trust, a charitable trust founded to help science students from less-well-off families, also provides funding to Isaac Physics (including a gift of GBP350,000 in 2018). Clare Harvey, Ogden Chief Executive, said: "We are really pleased to be involved with Isaac Physics….The continued, and growing, engagement with the platform by teachers and students is really encouraging and the feedback shows what a positive impact Isaac Physics is having on those who use it” [E6].

Impact 3: enabling teachers to reduce their workload, freeing time to develop skills and produce quality physics lessons.

Teachers can use the Isaac platform to set, mark and report homework, saving thousands of labour hours monthly. Most teachers feel their marking workload is too great, and cite workload as a major reason for leaving the profession [E7]. The Isaac platform has a direct impact on improving teachers' workload. Teachers who use Isaac have self-reported an average reduction in workload of 3.8 hours per week which in turn frees up time for improving teaching and learning [E1]. The School Standards Minister, Nick Gibb, commented in 2018 that "Isaac Physics, which the government funds and supports, has already helped thousands of teachers to deliver high quality physics lessons" [E6]. Teachers also report that the platform and associated outreach events like the Teacher Symposia help to develop their own knowledge of physics and their teaching abilities [E8]. A female teacher of Physics to A level at an academically non-selective state school commented: "first and foremost, this has given me a chance to upskill and therefore it has a direct impact on my teaching practice" [E3]. Another teacher commented that the symposium "was useful to gain a better insight into the functionality of Isaac Physics. I had not been aware of many of the features and I can now see much more clearly how to embed it in my teaching and make the best possible use of it" [E8]. Analysis shows that teachers who set and track student homework using Isaac also answer questions themselves to enhance their own problem-solving ability and subject knowledge [E3].

Impact 4: expansion to Computer Science

Building on the success of Isaac Physics, the University and the Raspberry Pi Foundation received GBP4 million in funding from the DfE in November 2018, to introduce Isaac Computer Science for A level students in England. The Isaac Computer Science platform uses the same underlying technology found in Isaac Physics and was launched in September 2019.

Over 30% of all A level computer science students in England are now using the platform [E9], and since its launch, over 2,200 teachers and 27,000 students have joined the Isaac Computer Science community [E10]. There are 39 separate topics and 527 questions on the platform, covering the whole A Level specification. Each question has three hints, with video support in the hints, and students have made in excess of 1.2 million question attempts. The platform also supports online and in-person events, and the project has run 55 events since September 2019, including 31 online in recent months, engaging 385 teachers and 710 students [E9].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[E1]. Isaac Physics Team report May – August 2019. See pages 1 and 4 of PDF.
[E2]. 2019 Lawrence Bragg Medal and Prize
https://beta.iop.org/2019-lawrence-bragg-medal-and-prize
[E3]. Isaac Impact and Engagement Summary April 2018. See in particular pages 1, 2, 3, 6, 8, 10 and 13 of PDF.
[E4]. Physics A Level Entries 2019. See page 8 of PDF.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803906/Provisional_entries_for_GCSE__AS_and_A_level_summer_2019_exam_series.pdf
https://cdn.isaacphysics.org/isaac/publications/impact_summary_201804_v6.pdf
[E5]. Gender Differences in Fear of Failure amongst Engineering Students
K.L. Nelson, D.N Newman, J.R. McDaniel, W.C. Buboltz: "Gender Differences in Fear of Failure amongst Engineering Students." International Journal of Humanities and Social Science. Vol. 3 No. 16. August 2013.
http://www.ijhssnet.com/journals/Vol_3_No_16_Special_Issue_August_2013/2.pdf
[E6]. Isaac Physics Funding – The Ogden Trust. https://www.ogdentrust.com/about-us/news/isaac-physics-funding
[E7]. DfE 2016 Report 'Eliminating unnecessary workload around marking'. See page 6.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/511256/Eliminating-unnecessary-workload-around-marking.pdf
[E8]. Isaac Physics Teacher Symposium Feedback July 2018. See pages 4 and 7 in particular.
[E9]. Isaac Computer Science GCSE proposal, August 2020.
[E10]. Isaac Computer Science statistics, 2nd December 2020.