JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

Organic Chemistry in Action! What Is the Reaction?

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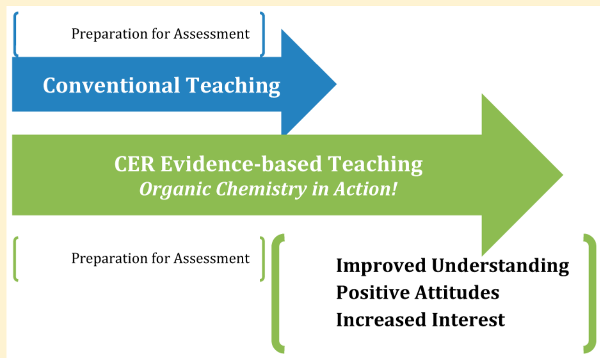
Supporting Information



ABSTRACT: The *Organic Chemistry in Action! (OCIA!)* program is a set of teaching resources designed to facilitate the teaching and learning of introductory level organic chemistry. The *OCIA!* program was developed in collaboration with practicing and experienced chemistry teachers, using findings from Chemistry Education Research (CER). The program was developed as an alternative mode of teaching the prescribed high school organic chemistry curriculum in Ireland. The program aims to improve learners' attitudes towards, interest in and understanding of organic chemistry. The *OCIA!* program has been trialed with 87 students in six high schools. The effectiveness of the program was evaluated using three methods: feedback from the chemistry teachers in the experimental group (n = 6), feedback from the students in the experimental group (n = 87) and quasi-experimental comparison with students in a control group (n = 117). The evaluation has shown that this project was effective in improving the students' attitudes towards, interest in and understanding of organic chemistry. This evaluation identifies the challenges and opportunities in implementing CER in designing Chemistry curricula for high school classrooms. The integration of CER in practice requires collaboration between all parties responsible for designing, teaching and assessing school Chemistry. It is hoped that the evidence from this intervention can be used to encourage the use of evidence-based best practice in high school chemistry classes internationally. The approach is also useful for introductory organic chemistry courses at university.

KEYWORDS: *High School/Introductory Chemistry, Organic Chemistry, Chemical Education Research*

FEATURE: Chemical Education Research

INTRODUCTION

Chemistry is perceived as difficult by many learners, and thus, many have a negative attitude toward the subject.[1−5] One of the greatest difficulties for novice learners in chemistry is being able to relate the macroscopic, submicroscopic and symbolic levels of chemistry.[6] In addition to these levels of understanding, learners need to be able to move between two-dimensional and three-dimensional representations using physical models and paper representations.[7]

There are three main facets of teaching and learning chemistry informed from CER: curriculum, pedagogy and assessment.[8] Too often, there is a mismatch between these three pillars, as only one of these, pedagogy, is in the control of the teacher. Previous research[9,10] has highlighted the importance of the role of the teacher in influencing student learning. The teacher should understand their learners' cognitive ability and have the necessary Subject Matter Knowledge (SMK) and Pedagogical Content Knowledge (PCK).[9,11] Teachers need to understand how their students learn in order to teach effectively.[12] The *Organic Chemistry in Action! (OCIA!)* was designed to facilitate co-operative learning using a combination of teaching methodologies. The use of mixed methods teaching approaches is an effective way of improving students' interest and learning.[13,14]

High school Chemistry in Ireland is a two-year course, taken by ∼15% of the total cohort of learners,[15] and is offered at two levels: higher and lower. Everyone studying high school Chemistry in Ireland must study the defined syllabus and sit the terminal state examination. Organic chemistry accounts for 20% of the current syllabus[16] and 25% of the terminal examination.[15] This examination is composed of 11 questions, where the students must answer a minimum of eight. Each question focuses on individual topic areas with the exception of one general question. The state examination determines students' progression to undergraduate level and is comparable to the Advanced Placement (AP) Chemistry Exam in the U.S. On average over 70% of candidates sitting the Irish Chemistry state examination achieve an A/B/C grade.[17] Likewise, approximately 55% of American high school students achieved a score of 3 or more in the AP Chemistry examination.[12] The concern[12] about the learners' level of conceptual understanding despite these high grades is currently being addressed in the US in the redefined AP Chemistry course.[18] Reflections on reform

DOI: 10.1021/ed5006163
J. Chem. Educ. XXXX, XXX, XXX−XXX

of the AP Chemistry course and the findings from the *OCIA!* intervention have potential to inform improvements in classroom practice and future curriculum development.

Recent reports[17,19,20] from the Chemistry Chief Examiner in Ireland have highlighted the students' poor level of attempt and performance in questions in organic chemistry. Organic chemistry is not compulsory in the examination and can be avoided. Except for the higher level question assessing fuels, the other organic chemistry questions are poorly answered and unpopular. None of organic chemistry questions are popular or well-answered by the lower level candidates. The most recent Chief Examiner's Report (2013) analyzed performance in respect of different levels in the cognitive domain: (i) knowledge and understanding, (ii) application and analysis, and (iii) synthesis and evaluation. Many candidates who answered parts of questions correctly were unable to were unable to answer the higher level questions.[17] Overall, the organic chemistry questions were better answered by the higher than the lower level candidates. The Chief Examiner's Report (2013) raised concern about the poor preparation of candidates for organic chemistry questions. Even though mechanisms are frequently assessed in the terminal examination, they are consistently poorly answered.

■ ORGANIC CHEMISTRY IN ACTION! (OCIA!)

The *OCIA!* program is a set of teaching resources designed to faciliate the teaching and learning of introductory level organic chemistry. The following organic chemistry topics from the high school Chemistry syllabus[16] are included in the program: sources, structure, physical properties and nomenclature of aliphatic (chloroalkanes, alkenes, aldehydes, ketones, alcohols, esters, carboxylic acids up to C4, alkanes up to C5 and ethyne) and aromatic (benzene, methyl-, and ethylbenzene) hydrocarbons, oil refining and its products, hydrogen as a fuel, saturated and unsaturated organic compounds, organic reactions (addition, substitution, elimination, redox and reactions as acids) extraction techniques (solvent extraction and steam-distillation) and the principles of instrumentation (chromatography, mass spectometry, gas chromatography, high-performance liquid chromatography, infrared absorption spectrometry and ultraviolet absorption spectrometry).

The *OCIA!* teaching materials include a Teacher Guide, two Student Workbooks and Teacher Resource Pack. The Teacher Guide contains the complete SMK and PCK to deliver the *OCIA!* program. The Student Worksbooks were designed with skeletal notes. This design facilitated the inquiry-based approach of the program. The program is appropriate for use with high school and introductory university level organic chemistry. The *OCIA!* program was developed by the authors in collaboration with high school chemistry teachers, chemistry education researchers and university chemistry researchers and educators. The program was reviewed by experienced high school and university chemistry teachers. *OCIA!* was planned as a 12 week teaching program, but elements of the program can be taught individually. The program was informed by previous research carried out by the authors[21] as well as other Irish[22] and international[23] Chemistry Education Research (CER). The difficulties that learners have with organic chemistry are multifaceted. For this reason, the authors designed the *OCIA!* program with varied methodologies for teaching organic chemistry. Nine key design criteria were used to develop the *OCIA!* program:

1. Spiraling & Drip-feed Introduction of topics: Chemistry needs to be taught in a way that allows learners to construct their own knowledge, rather than simply memorizing unrelated, and poorly understood facts.[24] "Drip-feed" means that the topics are introduced on a "need-to-know" basis to prevent memory overload.[25] This approach involves separating organic chemistry content into cycles, rather than consecutive topics.[26−28]
2. Linking Learning Outcomes and Assessment: This facilitates the teacher and learner in evaluating what has been learned.[29] Reviews, summary classification charts and concept maps prompted learners to assess their learning at the end of each lesson and unit.
3. Formative and Summative Assessments: Classroom activities, online tools, games, classroom response cubes and worksheets were used to assess the learning throughout the program.[30]
4. Facilitating Cognitive Development: Many novice learners operate at the concrete level but much organic chemistry requires formal cognitive operations.[24] Concrete activities were used to facilitate learners in bridging the gap to abstract understanding.[31−33] Teaching materials appropriate to the cognitive ability and working memory space of the learners can have a positive influence on learners' attitudes and understanding.[5,34]
5. Guided Inquiry Learning: Prompting questions and discussion points were used to scaffold learners' understanding. Inquiry learning helps the learners to move away from memorization and more toward mastery of fundamental concepts.[35−37]
6. Visual Aids: Molecular models, molecular diagrams, animations,[38] powerpoints and videos as well as concrete resources, e.g., plastic building blocks, colored beads etc. were used to facilitate understanding.[39,40] The use of modeling helps to increase the learners' understanding and retention of the topic by enabling them to picture the chemistry as it happens.[41]
7. Applications-led and Context-based Chemistry: Unfolding the necessary organic chemistry content through everyday applications and contextual examples facilitates the learners' understanding of and interest in the subject.[1,42−44] Two-page *Chemistry Chronicles* with everyday contextual links to organic chemistry are included at the beginning of each unit of work in the *OCIA!* program. These articles help teachers and students to shift to a more conceptual and inquiry-based approach.[45]
8. Integration of Practical Work: The program provided especially designed short practical activities that could be easily integrated with theory as student activities or teacher demonstrations. These included alternative approaches for the mandatory experiments[16] as well as nonmandatory experiments. Prelaboratory and postlaboratory exercises were also included to facilitate understanding of the practical experiences.[6,23,46−48]
9. Identification and Addressing Misconceptions: Possible learner misconceptions for each topic were listed in the Teacher Guide. Appropriate activities were included in the Student workbooks to help the teacher to identify and address the learners' misconceptions.[9]

The design and development of the *Organic Chemistry in Action! (OCIA!)* program has been described in detail with exemplar material in a previous issue of *J. Chem. Educ.*[49] The

DOI: 10.1021/ed5006163
J. Chem. Educ. XXXX, XXX, XXX−XXX

complete *OCIA!* program was implemented by six high school chemistry teachers in six different Irish high schools. This paper reports this implementation and evaluation as an intervention project. Since its development in 2012, different parts of the *OCIA!* program have been trialed by a number of high school and university chemistry teachers.

■ METHODOLOGY

Research Questions

The *OCIA!* program is a synergy of CER and the curriculum content prepared for a specific purpose: to improve interest in, understanding of and attitudes toward organic chemistry.

This research aimed to investigate the effectiveness of the *OCIA!* program:

1. What effect can a specific evidence-based teaching program have on high school students' attitudes toward and interest in organic chemistry?
2. What effect can a specific evidence-based teaching program and resources have on the high school students' understanding of organic chemistry?
3. What are the specific opportunities and challenges associated with effective use of the *OCIA!* program?

Participants

The teachers involved in this research were self-selected and identified from a previous study of high school teachers and students from a random sample of 73 high schools.[21] The participating students were those in the Chemistry teachers' classes. The cost involved in providing the resource materials limited the number of schools who could be involved. While the authors recognize that a larger number of participants would substantiate the findings, this was not feasible. The experimental group included six teachers and 87 students. Four of the schools were co-educational and two were all-girls: 35 (40%) of the experimental group students were male and 50 (58%) were female, with two students not indicating their gender. Five of the six teachers in the experimental group were female and one male. The students (n = 117) in the control group were from different nine schools. Five of these schools were co-educational, three were all-girls and one was an all-boys school: 41 (35.0%) of the control group students were male and 74 (63.2%) were female, with two students not indicating their gender. The higher proportion of females than males in the sample participants is representative of the national proportion of students studying high school Chemistry, averaging 57% female and 43% male over the past 5 years.[17]

Demographic data (school type, gender, level of Mathematics and Science studied in lower high school, level of Mathematics and Chemistry that they were currently studying in upper high school as well as information about other science subjects that they were studying) was used to check the equivalence of both groups of students. The Pearson Chi-Square test was used to investigate if there were any significant differences between both groups for each of these factors. It was found that the only significant difference was in school type (χ^2 = 21.195, p < 0.001). This was expected as there was no all-boys school in the experimental group and there was one in the control group. Both cohorts were suitable for comparison as their Science and Mathematics backgrounds showed no significant differences. However, a higher percentage of the control group than experimental group studied higher level Science, Mathematics and Chemistry. This suggests that the control group may have been higher ability students as they had a stronger background at the beginning of their study of organic chemistry. Only 157 (76.9%) of the participating students indicated their Science and Mathematics grade level from lower high school. Although the Pearson Chi-Square test showed no significant difference in the grade levels between both cohorts for Mathematics (χ^2 = 8.162, p = 0.418) or Science (χ^2 = 3.218, p = 0.781), a greater percentage (>5%) of the control group than experimental achieved A grades in both these subjects. Both groups of students were involved in a quasi-experimental comparison.

Implementation

The *OCIA!* intervention was implemented in the fall of the second year of the two-year high school Chemistry course, as this is the time when most teachers teach organic chemistry.[21] The teachers in the experimental group had a half-day professional development workshop before the intervention. At this workshop, the researchers outlined the design criteria and the philosophy of the *OCIA!* program. The high school Chemistry teachers were practitioners and it was important to outline relevant CER. Theory informs practice but practice can refine theory.[50] By sharing results from CER with the teachers, it was hoped that this would facilitate their implementation of the *OCIA!* program. The teachers experienced aspects of the *OCIA!* program from the perspective of a learner. Each teacher collected their own Teacher Resource Pack at the workshop. One of the researchers visited each of the experimental schools during the implementation. Classroom observations and one focus group were carried out during these visits. An online forum was also set up to access the *OCIA!* resources.

Evaluation

The authors of this paper were both the developers and the evaluators of the *OCIA!* program. The lack of an external evaluator may weaken any claims made for the intervention.[51] Previous Chemistry intervention programs[29,43,44,52] have been internally evaluated, and there are advantages in having the developer involved as the evaluator. They have a clearer sense of the key features and of the outcomes of the program.[53]

It is important to distinguish the difference between evaluation and assessment.[54] An intervention can make a change in the classroom environment without having any significant effect on examination performance.[54] While the performance in an Organic Chemistry Test for Understanding was compared with a control group, other methods of evaluation were also used. The researchers have experience (A.O'D., 5 years; P.C., >40 years) in teaching and tutoring Chemistry teachers. For this reason, it was decided not to explicitly observe the control group in this study to avoid the Hawthorne effect.[55] Anecdotal evidence and previous research[21] provided sufficient evidence that much classroom teaching lacks many of the key criteria of the *OCIA!* program.

A mixed methods approach was used (Figure 1). The qualitative techniques helped the researchers to look beyond the simple question of 'Did the students like the idea?' to instead looking at whether the intervention had an effect on classroom practice. Research[56] advocates the use of multiple sources at several times during the intervention and evaluation. The student (n = 36) and teacher (n = 6) questionnaires were piloted in 4 different schools and revised before implementation of the *OCIA!* program.

The classroom observations provided the researcher with feedback about the implementation of the *OCIA!* program. Two different student questionnaires were used in the

DOI: 10.1021/ed5006163
J. Chem. Educ. XXXX, XXX, XXX−XXX

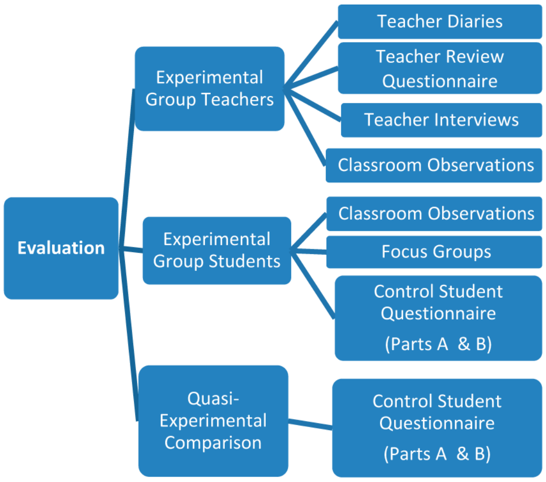


Figure 1. Evaluation of the *OCIA!* program.

evaluation of the intervention program. The *Experimental Student Questionnaire* was distributed to the students who participated in the *OCIA!* intervention.

This questionnaire had three parts:

- **Part A:** Demographic information and attitudes toward organic chemistry.
- **Part B:** Organic Chemistry Test for Understanding.
- **Part C:** Evaluation of the *OCIA!* program.

The *Control Student Questionnaire* was distributed to students in the control group. This questionnaire had two parts: these parts A and B were identical to parts A and B described above. Parts A and B of both student questionnaires were analyzed together and used to compare the attitudes and content knowledge of both groups of students. The *OCIA!* evaluation toolkit is included in the Supporting Information.

Experimental Group Teachers

The classroom observations and teacher diaries were completed during the implementation phase. The teacher questionnaire and interviews were completed after finishing the *OCIA!* program. The consistency in the data collected from using the different tools confirmed the temporal stability of the evaluation.[57]

The formative data (classroom observations and diaries) gathered during the intervention was useful for informing the development of the summative evaluation tools (questionnaire and interview). A rubric was designed for the classroom observations. The purpose of the classroom observations and the focus group were to evaluate the implementation and effectiveness of the *OCIA!* program rather than the behavior of the participants. For this reason, the *OCIA!* design criteria[49] were used to develop the rubric. Each criterion was assessed as observed (yes/no) and additional comments included. Some observations involved the use of the *OCIA!* resources. Other observations focused on the perceived engagement with the *OCIA!* program.

The teacher diary had a list of prompting questions at the beginning to stimulate the teachers' reflection after each lesson. The reflection in the teacher diaries was focused on the *OCIA!* materials rather than the teachers' personal professional development as a teacher. These included identification of the strengths and weakness of the lesson, teaching strategy, activities etc., perception of students' experiences, parts of the lessons, Teacher Guide or Student Workbook that they would change if repeating the lesson, etc.

The teacher questionnaire was divided into three parts. The first part was a 5 point Likert rating scale, where the teachers rated the usefulness of specific *OCIA!* resources, student workbooks, practical activities, teacher guidebook and contextual links. The ratings were 1 = Really helpful, 2 = Helpful, 3 = Unsure, 4 = Not Helpful and 5 = Really not helpful. With the use of the same Likert ratings, the teachers also rated the teaching strategies used in the program. The final section of the teacher questionnaire was composed of 11 open-ended questions about the program.

The individual semistructured teacher interviews were carried out after completion of the questionnaire and diary. This allowed the researcher to enquire about any issues with the individual teachers to ensure respondent validation.[57,58] The triangulation of qualitative and quantitative evaluation techniques was useful to confirm the teachers' feedback.[59]

A structured topic guide[60] was prepared following deductive analysis of the teacher questionnaires, teacher diaries and classroom observations. The topic guide contained the key themes to be explored in each of the six individual teacher interviews. The topic guide (included in the Supporting Information) was used to develop the core questions for the semistructured interviews. This was important to maintain consistency in the wording and ordering of questions to avoid any bias.[61] Some individual questions were asked following the deductive analysis of the other data (classroom observation, diary and questionnaire). The questions were divided into themes: resources, perceptions of students' experiences, personal teaching approaches, challenging topics to teach, implementation of practical work, inclusion of games and overall impressions. The researchers were familiar with the *OCIA!* program and content, had observed the program during the implementation phase and analyzed the collected data. This background knowledge gave the researchers the competent skills of a good interviewer.[62] The researchers were able to validate the interview responses by comparison with the other data collected. The qualitative data from the teachers was transcribed and coded systematically to identify emerging themes.[63] Specific domains were developed, where related items and comments were grouped, e.g., teachers' attitudes, perceptions of students' experiences, approaches taken to teach difficult organic topics, effectiveness of the *OCIA!* design criteria, development of students' understanding, focus on external issues, e.g., syllabus, examinations, etc. Relationships and inferences were established between the defined domains. In summarizing the key issues and main findings from the teacher interviews, the researchers were cautious to seek discrepant cases in the data so as not to simply support the hypothesis that the *OCIA!* program would have a positive impact on the teaching and learning of organic chemistry.

Experimental Group Students

The classroom observations and focus group were carried out in the classrooms implementing the *OCIA!* program. As explained earlier, the classroom observations were focused on *OCIA!* criteria.

One of the researchers held a focus group with one class of students (co-educational school, $n = 7$, 4 m, 3 f). This was held in the classroom when the students were halfway through the *OCIA!* program. The teacher was present during the group discussion. The researchers acknowledge that the teacher's

DOI: 10.1021/ed5006163
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Table 1. Content, Source, Style, and Complexity Level of the Organic Chemistry Test for Understanding

Question	Topic (syllabus section)[10]	Source	Style	Level of Complexity[67]
1	Drawing (5.2, 7.1, 7.2)	Researcher	Closed- Fill in the blanks Free Drawing response	Level 2 –Facts
2	Nomenclature (5.2, 7.1, 7.2)	Researcher	Open-ended with direct instruction	Level 2 -Facts
3	Nomenclature and Isomerism (5.2, 7.1)	Modified by researcher[65]	Closed response Structural Communication Grid	Level 2 -Facts
4	Predicting Organic Reactions: Electron Density (7.3-a)	Modified by researcher[66]	Open-ended with direct instruction	Level 3 -Processes
5	Organic Synthesis (7.3)	Researcher	Closed- Fill in the blanks Free Drawing response	Level 4 -Linear Causality
6	Reaction Mechanism (7.3-a)	Researcher	Open-ended Free Drawing response	Level 5 -Multivariate interdependencies
7	Classification (functionality) (7.1, 7.2)	Researcher	Closed response	Level 2 -Facts
8	Physical Properties (7.1)	Modified by researcher[66]	Two-tiered MCQ	Level 4 -Linear Causality
9	Shape and Structure (7.1, 7.2)	Researcher	Open-ended with direct instruction	Level 4 -Linear Causality
10	Reaction Scheme (7.3)	State Examination[64]	Open-ended with direct instruction	Level 5 -Multivariate interdependencies

presence may have influenced the student's discussion. The teacher's influence was limited as the discussion was focused explicitly on the *OCIA!* criteria rather than the teacher's practice. The criteria on the classroom observation rubric were used to prompt the discussion. The students provided feedback about practical issues of using the *OCIA!* student workbooks, such as limited space to accommodate for the size of students' hand writing and the grayscale throughout. The students also provided specific comments about contextual links in previous lessons that they recalled and enjoyed and about the use of specific *OCIA!* resources.

The *Experimental Student Questionnaire* was completed by the students when they had finished the *OCIA!* program. Part C of this questionnaire allowed the students to rate the helpfulness of the different aspects of the program. The students rated the specific criteria of the *OCIA!* program on a five point Likert scale (1 = Really Helpful, 2 = Helpful, 3 = Indifferent, 4 = Not Helpful and 5 = Really not helpful). The rating scales had a very good level of internal consistency (Cronbach α = 0.881).

Quasi-Experimental Comparison

The questionnaires (*Experimental Student Questionnaire* and *Control Student Questionnaire*) were completed by the (experimental and control) students when they had finished their study of organic chemistry. As well as providing demographic data, Part A of the student questionnaires had a five-point Likert rating scale (1 = Really Easy, 2 = Easy, 3 = Neutral, 4 = Difficult and 5 = Really Difficult) where the students rated how easy/difficult they found different organic chemistry topics. The topics were named as they appear in the high school syllabus.[16] The scale on the revised questionnaire used for the quasi-experimental comparison had a high level of reliability (Cronbach α = 0.923).

It was important that the content in Part B of the student questionnaires (Organic Chemistry Test for Understanding) was verified by expert content review.[56,57] Three experienced chemistry education researchers and a practicing high school chemistry teacher reviewed the test. The high school syllabus[16] determined the topics included on the test and was used to assign the criterion-referenced marking scheme. All students would have covered the same content, albeit in different ways.

There were 10 questions in this test (Table 1). Some questions were designed by the researcher others were adapted from other sources.[64−66] Question 10 was taken directly from a previous state examination paper.[64] For the test to be valid, it was important that the questions used had not been seen or practiced by the students prior to testing. For this reason the examination question used was not from recent examination papers. Due to the specific nature of the test, other questions available in the literature were not suitable. Five levels of hierarchical complexity[67] were used to categorize the questions. All questions in the test were evenly weighted (10 marks each).

Many closed questions were used, which were useful to generate frequencies of responses for statistical analysis, and to make comparisons. These questions were easier to code than open-ended questions.[68] Open-ended questions were more useful where the range of responses were unknown to the researchers. Although question six was a free−response question, some guidance was given i.e. use arrows to map electron movement. When this was not specified in the pilot, most respondents simply completed the reaction equation, without showing the mechanism. This Organic Chemistry Test for Understanding was specifically designed to test the students' understanding of concepts in organic chemistry and not simply as a recall of content.

The *Control Student Questionnaires* and the *Experimental Student Questionnaires* were anonymous and the participating schools were confidential to the research gatekeeper. This eliminated any bias in the correction of Part B of the questionnaires. The Guttman Split-half test was used to test the reliability of questions in the Organic Chemistry Test for Understanding. This test is used to estimate the full test reliability based on the reliability of both halves of the test. In this test the questions were divided into two parts; questions one to five and questions six to ten. The Guttman split-half coefficient score was 0.850. Cronbach α for part 1 of the Organic Chemistry Test for Understanding (Q1−5) was 0.815 and for part 2 (Q6−10) was 0.836.

The researchers recognize that the findings could have been validated by using cognitive interviews.[57] However, many of the questions did provide space for free responses which was a helpful source of validity.[57] An anonymous sample of tests (58 from control group, 42 from experimental group) was marked

DOI: 10.1021/ed5006163
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by an experienced Chemistry Education researcher (not involved in the study). Both raters used a prescribed marking scheme. The inter-rater reliability was found to be substantial: Kappa = 0.637 (p <0.001).

■ RESULTS

Teachers in the Experimental Group

The individual teachers were consistent in their feedback given through each method of evaluation. The observations and diaries provided some feedback about the implementation of the *OCIA!* resources. The open-ended questions in the questionnaire and interview gave teachers an opportunity to provide further detail about their experiences of the program. Data including extracts from the transcribed interviews and diaries are collated here to provide an overview of the teachers' experiences illuminating the parts of the *OCIA!* program that teachers found challenging, unnecessary and most effective.

Although the participating teachers were provided with all of the necessary *OCIA!* resources, personal time was required in preparation for implementation: *"Very good program, but presenting someone else's work was greatest difficulty for me (after 26 years of my own approach)"* (Diary- Teacher A). In addition to this preparation time outside the classroom, finding time for complete implementation within the classroom was a challenge also. All of the teachers reported that the time taken for complete implementation of the *OCIA!* program (up to 16 weeks) was beyond allocated[16] time (12 weeks). In some cases, the teachers had to 'tell' the students the answers to record in their Student Workbooks (which were largely composed of skeletal notes). In the interview, Teacher C explained *"they [students] did get that message that like everything is related to Organic. They really did... Like I think they were really interesting"*. However, Teacher C continued *"But a lot of that... is not relevant, not on the syllabus"*. Some teachers provided summary 'study notes' for the topics. *"I found that the students had trouble understanding what they needed to know at the end of the lesson"* (Diary-Teacher E, Unit 4, Lesson 1).

Despite the concerns raised about the time constraints, some teachers were happy to spend more time to complete the *OCIA!* program. *"I knew I was behind with it [organic chemistry] and I was like I am still finishing the book [OCIA!] the way it is...I'm not [rushing it] because as I said, I found it so good...it has changed my attitude to teaching it [organic chemistry] "* (Teacher G interview).

There were mixed responses to whether the *OCIA!* program benefited higher and lower level students equally. Four of the teachers felt that spiralling topics and visual aids were more beneficial for the lower level students. *"The better ones [higher level students] didn't like it and the weaker ones [lower level students] did is the truth...Because things were nice and slow, and because they got to handle stuff"* (Teacher A interview). While two of the teachers felt that the higher level students found this approach boring, they did recognize the benefit of revising prerequisite topics such as bonding, electronegativity etc. One teacher felt that the program was better suited to higher level students only as some of the content and inquiry-based activities were too difficult for the lower level pupils to understand. One teacher felt that the spiral nature of the program benefited students of all abilities. Despite this diversity, all of the teachers appreciated that the *OCIA!* program facilitated understanding as summarized by Teacher D: *"I have a class of mixed ability, and the higher level students probably benefited more and the lower-ability pupils will find it [organic chemistry] that··· just that slight bit more difficult. But 100%, for a conceptual understanding of Organic Chemistry, there is no comparison between teaching it in this way [OCIA!] and teaching it as from the old Leaving Certificate [state syllabus] course. No comparison, definitely no comparison"* (Teacher D interview).

The main concerns raised by the teachers were related to their focus on preparing pupils for the terminal state examination, the time constraints and the specific use of some resources that they found to be ineffective. Some teachers omitted parts of the *OCIA!* program which were beyond the scope of the high school syllabus, despite their inclusion to facilitate understanding. *"Arrows [in reaction mechanisms] are not needed in LC [state examination], so I told them to leave them out"* (Teacher C interview). However, other teachers were happy to spend more time teaching the *OCIA!* program to facilitate student understanding. The teachers also omitted some of the nonmandatory teacher demonstrations which were included. While the teachers commented that these demonstrations were good, they had not the time to implement them with their exam classes.

In the observed classes, each of the teachers used the *OCIA!* resources (classroom response cubes, plastic building blocks, molecular models etc.) and pedagogies (demonstrations, PowerPoint illustrations, analogies, writing on the whiteboard, group work etc.) *"So, from their [the pupils'] experience, in terms of the visual aids, in terms of the PowerPoints and in terms of what they are actually doing in class with the models and the experimental work, it absolutely 100% enhanced their learning. Definitely...I don't think there is anything else that I would have added to make it any more student friendly for them"* (Teacher A interview). The teachers found the homework assignments and learning summaries very useful for formative assessment. *"The past exam papers cannot be used until you are finished the Organic, so it is great to have some form of assessment before that...there isn't much in the book* [textbook]*"* (Teacher C Interview).

The spiral nature of the *OCIA!* program was evident in each of the observed lessons, as the teachers probed the students' prior knowledge to develop further understanding. Each of the teachers addressed the possible misconceptions that the pupils may have had using the tools and guidelines provided. Teacher D felt that Organic Chemistry lends itself well to a spiral structure: *"I think that I like the idea of the spiral thing, like coming back to it and doing it again. I might try do that again. You know like split those chapters up, because I think it's the trying to learn the whole lot together, trying the whole lot in one go, is the hardest thing for students"* (Teacher D interview).

The teachers were very positive about the use of the molecular models: *"Getting pupils to build models of dehydrogenation and hydrogenation was very good"* (Diary-Teacher G, Unit 2, Lesson 3). The widespread use of molecular models (beyond simply isomerism) in teaching about the structure of benzene, pi bonds, reactions and mechanisms facilitated understanding of these topics. There was just one instance recorded where the use of the models was not beneficial for one teacher: *"Pupils got distracted during the model-making—drawing would have been more useful [introduction of chloroalkanes]"* (Diary- Teacher E, Unit 4, Lesson 2).

The teachers realized that using different teaching approaches facilitates the students' understanding. *"Analogy with lego and sandwiches was very good in explaining limiting reagent, they really got it"* (Diary- Teacher G, Unit 7, Lesson 4). *"I like that focus is put on why alkenes react, rather than "learning*

DOI: 10.1021/ed5006163
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the mechanism" as it allowed the students to apply knowledge to additional reaction not on the syllabus" (Diary- Teacher E, Unit 6, Lesson 4). "*It* [OCIA!] *really got them [the students] up in terms of thinking about the mechanism and it questioned...I think the... just the way the workbooks were laid out for them and the assignments that were given for the Higher Level students was fantastic. They just got it*" (Teacher D interview). The teachers acknowledged the effectiveness of the models and games that were incorporated into the lessons "*it was good, having models for them to build it through to explain mechanism and getting them to figure out termination, they liked the card game to go with it too*" (Teacher G interview).

All of the teachers valued the context-based approach to the topics: *"I think that for the first time, they got everyday organic chemistry, they got examples, like making it applicable to everyday life..."* (Teacher E interview). There were many comments in the diaries also to support this: "*Fantastic applications included from everyday Science in material presented. Students engaged well*" (Diary-Teacher D, Unit 2, Lesson 4) "*Very modern, very relevant, even picked up some information myself*" (Diary-Teacher B, Unit 1, Lesson 2).

The structure of the Pupil Workbook was helpful in facilitating the pupils' understanding and preparation for the practical work. For example labeling diagrams of the set-ups; labeling the apparatus and also the reactants and products collected. In the Teacher Questionnaire, all of the teachers expressed their intent to use the *OCIA!* resources (Teacher Guide, Pupil Workbook, Resources Pack), practical activities and contextual links in their future teaching.

All of the teachers agreed that the *OCIA!* program had helped in improving their own and their students' understanding. *"If I had to start thinking about where the electrons are going... You're talking what about 12−13 years since I have written a red* [mechanistic] *arrow, so I... if I had to teach it, I would have to sit down and seriously... Just try drag it out of somewhere at the back of my head"* (Teacher C interview). As well as agreeing that the *OCIA!* helped in developing their own content knowledge, the teachers felt more aware of the possible learner misconceptions in organic chemistry. By understanding these, the teachers felt better prepared to facilitate student understanding. "*We want them to be interested in it too. I know now before this Organic wouldn't have been my favorite and now I like better now myself, and that's a good thing*" (Teacher B interview).

Most of the teachers agreed that "*the repetition [spiral curriculum] is helpful but the workbook needs to be condensed*" (Diary- Teacher B, Unit 4, Lesson 4). Teacher C related to with the students' perception of using two workbooks for one section of their high school Chemistry course: "*... and the kids found it a little bit daunting when they saw the two booklets*" (Teacher C interview). Revising the *OCIA!* program will be challenging to balance the syllabus content with contextual links to facilitate student understanding and interest. There was some difference in the teachers' recommendations to change the Student Workbooks: "*I suppose what I would make it··· is what's going to be examinable, say like I would take it from that, and then add in some of the other little bits··· But then maybe that is the wrong approach, I don't know*" (Teacher B interview). "*I actually think that it* [Student Workbook] *is quite user-friendly. Like I mean the blanks are left there for them. You have kind of you know··· spider diagrams, you have less··· You have a way of connecting one thing to another, and I think that's really nice*" (Teacher D interview).

The teachers shared their own ideas for teaching some of the organic topics. Teacher A recommended using "show-me" boards (small whiteboards) when teaching mechanisms. Teacher E recommended that the students collate a photo journal of their laboratory experiments. In the teacher questionnaire, all of the teachers were intent in using most aspects the program in their future teaching of organic chemistry. *"Well, as I said, it's different and I definitely intend to use it again. And I have actually learned a lot from it. Even in terms of making references to everyday things, you know? ... The simple demos that you suggested that I would never in a million years have thought of"* (Teacher D interview) and "*Like some of the pupils were even asking me would I use it again?... And yes, I would use it again next year definitely*" (Teacher G interview). Some teachers expressed intent in personalizing elements of the program. *"I prefer to make up my own stuff [teaching resources]., and I incorporate bits of everything in. But I like the stuff that I use to be my own. And I like making my own worksheets, unless I find a really good worksheet like, there is no point in re-inventing the wheel....you know it's more fluent when you have made them [teaching resources] up yourself and you understand it a lot better."* (Teacher E interview).

The teachers suggested a broader dissemination of the *OCIA!* program and resources and recommended integrating other Chemistry topics such as thermochemistry into the *OCIA!* program. All of the teachers agreed that the teaching approaches used in this program could be implemented in other areas of Chemistry: in particular with relation to the mole concept, chemical equilibrium and rates of reaction as well as in their teaching of Science.

Students in the Experimental Group

During the observed lessons, the students worked cooperatively when using the molecular models. The students were able to recall and apply previous knowledge, e.g., IUPAC naming, intermolecular forces, etc. where necessary to facilitate their understanding of subsequent topics. They engaged in the context-based discussions. Students in the focus group (school B) were enthusiastic about the practical work. The students in this class had completed all of the practical work (including the nonmandatory experiments and demonstrations) at the time of the focus group. As well as appreciating the hands-on experience of organic chemistry for themselves, they also recalled the teacher demonstrations with enthusiasm and detailed depiction. The pupils recalled and described the Pringles rocket (combustion of methane) and Carbon Tower (dehydration of sugar with sulfuric acid) demonstrations as 'cool'. As well as increasing the students' interest and attitude toward Chemistry, the practical work was effective in facilitating understanding. The students were vivid in their description of their observations-what they saw, what it smelled like, what worked well, why others did not work well, etc. The students in the focus group referred to the molecular models and plastic building blocks a number of times. This evidence suggests that these were used in almost all of the lessons. The students described the workbooks and animated powerpoint presentations as 'more fun' than the textbook. The students in the focus group admitted that they had perceived organic chemistry as a difficult topic before beginning their study of it. They were surprised with how relevant it was to their own lives. The students in the focus group appreciated the spiral curriculum. They referred to it as 'useful revision' of topics and 'easy to build up new ideas'.

DOI: 10.1021/ed5006163
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Table 2. Experimental Students' Rating of OCIA! Materials

OCIA! Materials		Median rating (n=83)	Mean rating (n=83)	Word rating
Resources	Molecular models	1	1.64	Really Helpful
	Playing cards	2.5	2.63	Indifferent
	Classroom response cube	2	1.86	Helpful
	Lesson Power Points	2	1.83	Helpful
	Videos	2	1.85	Helpful
	Animations	2	1.82	Helpful
Pupil Workbook	Order of lessons and topics	2	2.26	Helpful
	Outline of lesson outcomes	2	2.39	Helpful
	Completing the workbook	3	2.68	Indifferent
	Homework Assignments	3	2.55	Indifferent
	'What have I learned'?	2	2.25	Helpful
	Important Note boxes	2	1.74	Helpful
	Word Spy	2	2.66	Helpful
	Summary classification charts	2	2.06	Helpful
Practical Work	Non-mandatory activities	2	2.23	Helpful
	Teacher demonstrations	2	2.05	Helpful
	Mandatory experiments	2	1.76	Helpful
Relevance and Interest	Links to everyday life	2	1.94	Helpful
	Links to Industry	2	2.09	Helpful
	Chemistry Chronicles	3	2.58	Indifferent
	Group discussions	2	2.32	Helpful
	'Interesting Insights'	2	2.37	Helpful

Table 3. Quasi-Experimental Comparison of Test Performance (Per Question)

Item	Topic	Intervention Group (n = 87)			Control Group (n = 117)			Mann–Whitney U Statistic (n = 204)	Sig. (p Value)
		Median	Mean	SD	Median	Mean	SD		
1	Drawing	7.0	6.86	2.71	8.5	7.85	2.37	3952.00	0.005[a]
2	Nomenclature	5.0	4.99	2.66	5.0	4.90	2.85	4958.50	0.752
3	Isomerism	8.0	6.14	3.15	6.0	4.89	3.84	4233.00	0.034[b]
4	Predicting Reactions: Electron Density	4.0	3.72	2.54	3.5	3.29	2.03	4641.50	0.281
5	Organic synthesis	4.0	3.90	3.41	4.0	4.00	3.26	4978.00	0.787
6	Organic mechanism	2.0	2.52	3.10	00.0	2.02	2.81	4759.50	0.395
7	Classification (functionality)	7.0	6.45	3.04	5.5	5.42	2.95	3997.00	0.008[b]
8	Physical properties	4.0	4.43	3.38	4.0	5.02	3.41	4554.00	0.189
9	Shape and structure	5.0	4.51	2.99	2.75	3.10	2.46	3691.50	0.001[b]
10	Reaction Scheme (Examination Q)	7.0	5.92	3.72	6.0	5.40	3.64	4671.00	0.312

[a]The control group performed significantly better than the intervention group. [b]The intervention group performed significantly better than the control group.

The students in the focus group felt that the inclusion of more 'notes', rather than questions would be helpful. The higher level students in particular were concerned about the length of time taken to complete the *OCIA!* program, given that organic chemistry is just 20% of their high school chemistry course.[16]

A total of 83 (95%) of the 87 students completed Part C of the *Experimental Student Questionnaire*. The students rated the components of *OCIA!* program on a five-point Likert scale (Table 2).

The Pearson Chi-square test was used to investigate if any of the following had an effect on students' feedback: gender, level of Chemistry and Mathematics that they were studying and performance in Science in lower high school. Despite the teachers' perceptions (outlined earlier) that the *OCIA!* program benefited higher and lower level students differently, the Chi-Square test showed no statistical difference in the attitudes of higher and lower level students on the rating scales listed in Table 2. The only significant difference in the responses was the gender difference in the attitudes toward the nonmandatory experiments (χ^2 = 7.307, p = 0.026). Twenty-four (86.0%) of the males rated these as 'really helpful' or 'helpful', while only 26 (55.0%) of the females had a positive rating about the nonmandatory activities.

Quasi-Experimental Comparison

The students in the experimental group were taught using the *OCIA!* program and the students in the control group were taught organic chemistry without the *OCIA!* program. Both cohorts completed the Organic Chemistry Test for Understanding at the end of their study of Organic Chemistry.

The experimental group performed better than the control group in the Organic Chemistry Test for Understanding. The distribution of the test results were analyzed using the Kolmogorov−Smirnov Test. The test performance of students in the experimental group (n = 87) was not normally distributed (mean score = 49.55; SD = 22.62, median score = 49.00; IQR = 41.50, p = 0.037). The test performance of students in the control group (n = 117) was normally distributed (mean score = 45.83; SD = 21.29, median score = 44.75; IQR = 35.00, p = 0.200).

DOI: 10.1021/ed5006163
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As explained earlier, the control group had a slightly stronger background (level of study and performance) in Science and Mathematics than the experimental group. The students in the experimental group outperformed the students in the control group in all questions except one (Table 3). The Mann–Whitney U Test was used to investigate the difference between both cohorts since the overall (n = 204) distribution of scores in the test was nonparametric (Kolmogorov–Smirnov statistic = 0.68, p = 0.022). The control group performed significantly better than the experimental group in the question assessing Drawing. The control group may have had more experience in writing and drawing structures than the experimental group. The control group may have used molecular (or other) models in individual organic chemistry topics.[21] However, the experimental group had a structured experience of working with three-dimensional models to facilitate cognitive development throughout the *OCIA!* program. The experimental group performed significantly better than the control group in the questions assessing Isomerism, Classification, and Shape and Structure. These differences may be credited to the use of the molecular modeling kits, which were integrated into most lessons in the *OCIA!* program. However, due to the multifaceted nature of the *OCIA!* program, it is difficult to identify precisely which specific strategies contributed to the improved understanding of the experimental group.

The final question on the Organic Chemistry Test for Understanding was a question taken from a previous state examination paper. The experimental group outperformed the control group in this question. This suggests that the *OCIA!* program was effective in preparing the students for the terminal state examination. More of the students in the experimental group (59.0%) than control group (52.1%) expressed confidence in attempting an organic chemistry question in the state examination.

The Chi-square test was used to investigate the significant differences in attitudes between both cohorts. More of the experimental group than control group found organic chemistry enjoyable to learn (χ^2 = 8.853, p = 0.012), easier to understand (χ^2 = 6.567, p = 0.087), and interesting (χ^2 = 8.0093, p = 0.156). The experimental group rated the following topics as significantly easier to learn than the control group: drawing (χ^2 = 6.413, p = 0.041), isomerism (χ^2 = 20.163, p < 0.001), classification (χ^2 = 11.995, p = 0.007), carboxylic acids (χ^2 = 6.286, p = 0.043) addition reactions (χ^2 = 15.237, p < 0.001), substitution reactions (χ^2 = 14.774, p = 0.001), elimination reactions (χ^2 = 11.692, p = 0.003) and redox reactions (χ^2 = 10.489, p = 0.006). There was no significant difference in the students' ratings of other topics. However, more students in the control group than experimental group listed Mechanisms (control group = 44.4%, experimental group = 30%), Reactions (control group = 38.5%, experimental group = 28.0%) and Functional Groups (control group = 33.0%, experimental group = 27.4%) as difficult organic chemistry topics. These particular topics have been identified as difficult in previous research.[21,66,69,70] The *OCIA!* program was effective in improving students' understanding and attitudes toward these topics, as fewer students in the experimental group identified these as difficult.

■ DISCUSSION

As outlined in the introduction, many students have a negative attitude toward chemistry. Taber[9] and Childs[10] acknowledge that a teachers' attitude can affect students' attitudes toward and interest in a subject. While all of the participating teachers were preparing their students for the terminal state examination, most of them recognized the importance of preparing the students with the skills to equip them for further study of Chemistry and to develop a positive attitude toward the relevance of organic chemistry.

The context-based approach was one of the most effective criteria contributing to the experimental group students' positive attitudes to organic chemistry. This was evident in the classroom observations and through discussion with the focus group students. Consistent with Reid,[1] Parchmann et al.[42] and Dale,[14] we found that the integration of applications and contexts as well as other active learning methodologies maximize the amount of content that the learner can remember and also contribute to a positive learning experience. Positive learning experiences can lead to positive learner attitudes. The findings from the teacher and student feedback provide evidence of the continual use of the molecular models throughout the *OCIA!* implementation. All of the other resources used provided scaffolding for cooperative learning experiences (through planned activities or through necessity of sharing resources). These findings support earlier research by Dougherty[13] that a cooperative learning experience results in improved attitudes and interest, as well as increased learning and retention. As outlined by Hussein,[5] the use of the specifically designed teaching materials in the *OCIA!* program, appropriate to the cognitive ability and working memory space of the learners, had a positive influence on the learners' attitudes. More of the experimental group than control group found organic chemistry easier to understand and one of the most interesting areas on the high school Chemistry course. The experimental group were more confident and positive about learning organic chemistry. Although the control group had a slightly stronger background in Science and Mathematics, the experimental group were more confident in their intentions to attempt a question on organic chemistry in the terminal state examination.

As recommended by Ingle,[24] the *OCIA!* program was designed to allow learners to construct their own knowledge, rather than simply memorizing poorly understood facts. Instead of being given definitions, *OCIA!* incorporated a guided inquiry approach as used by Barke et al.[37] This facilitated the students in developing their own understanding. Consistent with Adey's[33] findings, the presentation and illustration of difficult topics in *OCIA!* through hands-on, inquiry-based activities facilitated students operating at the concrete stage of cognitive ability. The possible student misconceptions for each lesson were outlined in the *OCIA!* Teacher Guide. New words and definitions were explained. This scaffolding[9] facilitated the students' independent learning. As outlined earlier in this paper and by Johnstone,[25] this introduction concepts and topics in a drip-feed manner helped prevent cognitive overload and facilitate understanding.

The experimental group outperformed the control group in the Organic Chemistry Test for Understanding (Table 3). The experimental group also performed better in the question (Question 10) from the state examination paper. This suggests that the experimental group may have been better prepared for the terminal examination. As well as the experimental students' performance in the Organic Chemistry Test for Understanding, the teachers also recognized that the students would be better prepared for less-predictable examination questions "*I think the exams are going to change, so absolutely, this should stand to a*

DOI: 10.1021/ed5006163
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good standard of student dramatically like in answering the exam questions... like a mechanism. So most definitely, I think this [OCIA] will aid their ability to examine an exam question with a little bit of thought behind it" (Teacher D interview). Such feedback from the teachers suggests that the *OCIA!* program was effective in increasing the high school students' understanding of organic chemistry.

Previous research from Tasker and Dalton,[38] Jones[39] and Fleming et al.[40] support the claim that the use of visual aids helped the *OCIA!* students to develop a holistic understanding of organic chemistry. The molecular models were the most popular and most used resource in the *OCIA!* program. Prior to this intervention, many of the teachers had only used models for demonstration purposes or in teaching isomerism.[21] The teachers learned to see the benefit and advantage of the frequent use of the models. The students in the experimental group showed a significantly better understanding and retention of molecular shape and structure. The research from Smith et al.[41] indicates that this may be attributed to the integrated use of models.

Johnstone[6] has explained the difficulties faced by novice learners in moving between the three levels of chemistry. These difficulties were addressed in the *OCIA!* program. As suggested by Hassan et al.,[7] the integrated use of molecular models, practical (laboratory) and written (pen and paper) tasks in the *OCIA!* program helped students to develop better understanding. Much CER[33,34] advocates the specific structuring of developmental tasks to scaffold the cognitive development of lower ability students. The structure of the *OCIA!* student workbooks supported the students' stepwise understanding of organic chemistry.

It is difficult to affirm the opportunities and challenges associated with the use of a program such as *OCIA!*[10,71] despite the involvement of practitioners in the developmental stages.[49] The *OCIA!* program provides a value-added method of teaching high school organic chemistry. This potential added value is two-fold: improved student understanding and attitudes and also improved teachers' SMK and PCK. The development of the teachers involved in the *OCIA!* program was not the focus of this paper but will be addressed in a future publication. It is important to reflect here on the challenges related to effectively implementing the program within the current high school system. Many of the teachers' recommended changes were determined by the prescribed state Chemistry syllabus and examination. Within the current system, innovative teaching approaches are vulnerable, as the outcomes (improved attitudes, understanding and examination performance) are beyond the outcomes required in the current system (examination performance). It is understandable that students and teachers are focused on the high stakes examination. This extrinsic motivation is not unique to the Irish school system and has also been observed in the U.K.[72] The *OCIA!* program was designed as a teaching program for the organic chemistry content of the Irish high school Chemistry syllabus.[16] The evaluation assessed students' attitudes, interest in and understanding of organic chemistry. The *OCIA!* program effectively prepared the students to answer a question on the state examination. However, successful examination performance is not the only desirable outcome of the *OCIA!* program. The opportunity for alternative outcomes has been highlighted in previous evaluations of other educational programs.[12,53] These additional outcomes such as improved understanding, increased interest and positive attitudes toward organic chemistry have been identified in the evaluation of the *OCIA!* program.

The opportunities associated with a broader implementation of *OCIA!* is dependent on a change in how Chemistry is taught and examined. In revising syllabi, appropriate teaching strategies need to be introduced. The spiral introduction of topics was well received by teachers and students in the *OCIA!* program. Such an approach facilitates the use of "anchoring concepts" and "big ideas" rather than traditional content focused curriculum content.[73] Furthermore, the introduction of improved teaching strategies and methods will only be implemented when the assessment methods are also changed. The revision of the AP Chemistry Course has made an explicit effort to give students a deep foundation of chemistry content and skills, to provide teachers with a precise, framework to deliver the course, and to provide university faculty with the confidence that students are prepared for progression to university level Chemistry.[74] The approach used in the *OCIA!* intervention also achieves these goals.

■ CONCLUSION

This paper details the teachers' and students' experiences of the *OCIA!* program. However, due to the multifaceted nature of the program, it is difficult to determine one key element contributing to its success. The authors believe that the effectiveness cannot be attributed to just one element of the program. Given the complexity of the difficulties of chemistry for novice learners,[25,75] coupled with the diversity of teaching and learning experiences, the evaluation of the *OCIA!* program has shown that a multifaceted, evidence-based approach is a successful way to facilitate understanding. We conclude from our results that the *OCIA!* program can be described as a "value-added" program. Traditional and evidence-based teaching strategies are not necessarily different ways of achieving the same learning, they are instead different routes to two different targets.

In addition to the results presented in this paper, the authors raise further implications for future CER:

- The feedback from the teachers who participated in the *OCIA!* program provides some evidence that implementing a CER-informed teaching program is in itself a source of professional development for teachers.
- Professional development focused on improving teachers' SMK and PCK has consequential benefits for their students. This was evident in the improved performance of the students in the experimental group.

All of the experimental teachers were intent on using the *OCIA!* program in the future. They also saw opportunities to use the resources and ideas in other areas of Chemistry and Science. Elements of the *OCIA!* program have been made available to teachers in Ireland though professional development workshops and in the UK through publications.[76,77] This dissemination of the stand-alone units of the *OCIA!* program empowers teachers to personalize the resources.

The *OCIA!* intervention has demonstrated the value of using CER to inform pedagogy, and the feasibility of repackaging a conventional curriculum by using evidence from CER to improve teaching and learning. The challenge is to incorporate these findings into a redesigned high school curriculum, so as to improve students' understanding, attitudes and achievement in difficult areas of Chemistry, such as organic chemistry. We conclude from our results that without specific and planned

DOI: 10.1021/ed5006163
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professional development, the vision of reform will not be realized.[78] There is opportunity to learn from the experiences of this trialed intervention and from other practitioners[73] and teacher educators[11,78] to allow CER to inform content, pedagogy and assessment.

■ ASSOCIATED CONTENT

Supporting Information

A mixed methods approach was used to evaluate the *OCIA!* program. The evaluation toolkit containing the Classroom observation rubric, Control Student Questionnaire, Experimental Student Questionnaire, Teacher Diary, Teacher Review Questionnaire and Teacher interview topic guide are available.This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The Irish Research Council and the Department of Chemical and Environmental Sciences, University of Limerick for support for the researchers. Eli Lilly and Merck Sharp & Dohme supported the provision of the *OCIA!* resources to the schools in the experimental group.

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DOI: 10.1021/ed5006163
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